

The interplay of unconscious processing and cognitive control

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Are you watching closely?

– Alfred Borden (The Prestige)

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Zusammenfassung

Das Ziel dieser Arbeit war es, sowohl den Einfluss von kognitiver Kontrolle auf unbewusste Verarbeitung, als auch den Einfluss unbewusster Verarbeitung auf kognitive Kontrolle zu untersuchen. Zunächst werden verschiedene Mechanismen und Ansätze zur Erklärung unbewusster Bahnung vorgestellt. Dabei werden perzeptuelle Prozesse sowie motorische Prozesse beleuchtet und mit Reiz-Reaktions-Verbindungen, semantischer Kategorisierung und dem Ansatz handlungsdeterminierender Reizerwartungen drei verschiedene Ansätze zur Erklärung motorischer Bahnung besprochen. Danach wird die Problematik der Grenzen unbewusster Verarbeitung dargestellt. Es werden Befunde vorgestellt, die Hinweise auf den Einfluss von aktiven Aufgabeneinstellungen sowie von Expertise auf unbewusste Verarbeitung geben. Als nächstes werden Ergebnisse besprochen, die einen über motorische Prozesse hinausgehenden Einfluss unbewusster Reize nahelegen. Dabei wird insbesondere auf den Einfluss auf Hemmprozesse, Aufmerksamkeitsausrichtung, die Aktivierung von Aufgabeneinstellungen und Konfliktadaptation eingegangen. Dann werden die Ergebnisse eigener empirischer Arbeiten vorgestellt. In Experiment 1 wurde gezeigt, dass die effektive Verarbeitung unbewusster Reize von Expertise abhängt, auch wenn sonstige Unterschiede zwischen Experten- und Novizen-Gruppen kontrolliert sind. Die Ergebnisse von Experiment 2 und 3 zeigten, dass die Absicht, bestimmte Reize zu nutzen, ein entscheidender Faktor dabei ist, ob diese Reize auch unbewusst einen Effekt entfalten können. Zudem wurde hier gezeigt, dass Aufmerksamkeitsverschiebungen durch zentral präsentierte, maskierte Pfeile ausgelöst werden können. Die Experimente 4 und 5 erweiterten diesen Befund auf Hinweisreize, die keine inhärente räumliche Bedeutung haben.

Hier konnte bestätigt werden, dass eigentlich endogen gesteuerte Aufmerksamkeitsverschiebungen durch unbewusste Reize induziert werden können. Die Experimente 6 und 7 zeigten, dass selbst ein zentraler kognitiver Kontrollprozess wie die Aktivierung verschiedener Aufgabeneinstellungen nicht bewusstseinspflichtig ist, sondern im Gegenteil durch unbewusste Stimulation in Gang gesetzt werden kann. Letztendlich werden diese Ergebnisse zueinander in Beziehung gesetzt. Es wird diskutiert, inwiefern das Konzept kognitiver Kontrolle und die Grenzen unbewusster Verarbeitung neu betrachtet werden müssen. Außerdem werden mögliche zukünftige Forschungsfelder in diesem Bereich aufgezeigt.

Abstract

The aim of this study was both to investigate the influence of cognitive control on unconscious processing, and to investigate the influence of unconscious processing on cognitive control. At first, different mechanisms and accounts to explain unconscious priming are presented. Here, perceptual and motor processes, as well as stimulus-response learning, semantic categorization, and the action trigger account as theories to explain motor priming are discussed. Then, the issue of the potential limits of unconscious processing is presented. Findings that indicate that active current intentions and expertise modulate unconscious processing are illustrated. Subsequently, results that imply an influence of unconsciously presented stimuli that goes beyond motor processes are discussed, with a special focus on inhibition processes, orienting of attention, task set activation, and conflict adaptation. Then I present the results of my own empirical work. Experiment 1 shows that the effective processing of unconsciously presented stimuli depends on expertise, even when potentially confounding difference between the expert and novice groups are controlled. The results of Experiments 2 and 3 indicate that the intention to use particular stimuli is a crucial factor for the effectiveness of these stimuli when they are presented unconsciously. Additionally, these findings show that shifts of attention can be triggered by centrally presented masked arrow cues. Experiments 4 and 5 broaden these results to cue stimuli that are not inherently associated with a spatial meaning. The finding corroborate that typically endogenously controlled shifts of attention can also be induced by unconscious stimuli. Experiments 6 and 7 demonstrate that even a central cognitive control process like task set activation is not contingent on conscious awareness, but can in contrast be triggered through

unconscious stimulation. Finally, these results are integrated and I discuss how the concept of cognitive control and the limits of unconscious processing may have to be reconsidered. Furthermore, potential future research possibilities in this field are presented.

1. Introduction

The human consciousness is maybe one of the last great mysteries that modern science cannot fully (and probably not even half) explain, and has been the topic of philosophical, theological, and scientific debate for a long time. The ultimate conundrum here is how our subjective experience of the world, our experience of color and sound, our feeling of touch, our suffering of pain and savoring of joy, and all other experiences that together form our conscious awareness of the world, can arise from our materialistic brain. “Why should physical processing give rise to a rich inner life at all? It seems objectively unreasonable that it should, and yet it does” (Chalmers, 2005, p. 3). Chalmers calls this the *hard problem* of consciousness. The *easy problem* of consciousness, in contrast, concerns the mechanisms in the brain that are underlying particular processes like deliberate control of behavior, processing and integration of information, or focusing attention. In other words, the easy problem is to exactly determine how the human brain functions. While the hard problem seems to be tangible on a philosophical level only, the easy problem can in principal be researched with scientific methods.¹

A question that is of obvious interest for psychological research due to its fundamental relevance for human cognition and behavior is the function of our

¹ Eric Koch from the Allen Institute of Brain Research, a research facility focused on investigating the brain on a cellular level through optogenetic methods, stated at the ASSC conference 2012 that the easy problem is in his opinion truly the hard problem. He thinks that if the easy problem can be solved, it will also solve the hard problem (in contrast to Chalmer’s view), but is not sure if it can be solved, ever. To illustrate the problem, which is the unimaginable number of cells and cell interactions, he presented a video that showed a journey through a section of a mouse brain about as small as a hair, and the different cells in it. This awe inspiring video can be found on <http://www.youtube.com/watch?v=I1WufkGy3iA> (search word “synaptaesthesia”; watch with sound on).

consciousness. Does our conscious experience serve any functional purpose, or is it just a byproduct of information processing that is very fundamental for humans on a subjective level, but is ultimately useless from a functional point of view? A very common assumption is that consciousness is strongly related to control processes. Basically, this stance assumes that without consciousness, our behavior would be restricted to inflexible stimulus-response-links (S-R-links), and accordingly that it is only our consciousness that allows us to act in a flexible way that is deliberately controlled. By varying the level of subjective awareness of a stimulus and investigating how this manipulation relates to other processes (and which moderating influences on this relation exist), one can investigate the role consciousness plays with the initiation and execution of these other processes.

The question to what extent unconsciously perceived stimuli can affect our behavior has been studied for over a hundred years. Sidis (1898) showed cards with numbers on them to his participants and asked them of their subjective awareness of what was printed on the card, and to guess what was printed on the card. Stuningly (at the time), he found that under conditions in which the participants reported that they could not see what was printed on the card, they could still name the printed number above chance level. This can be seen as a first result that showed that a conscious representation of a stimulus is not a prerequisite for the stimulus to be processed (and exert an impact on us). While such results are intriguing, this study also exemplifies the problems that come naturally with this kind of research, namely how to determine whether the stimulus was in fact not consciously perceived. One line of research made use of clinical samples with patients that show neurological deficiencies like neglect, extinction, or blindsight, which prevent the patients from perceiving stimuli although the

stimuli are in principal clearly visible. For example, participants with visual neglect read words faster when the words were presented beforehand in the participants' blind field. Again, although no subjective awareness of the presented words was expressed, the stimuli were processed and influenced behavior.

Another possibility to investigate unconscious processing is the masked priming paradigm (Marcel, 1983). In this paradigm, the impact of a masked stimulus – the so called prime – on the processing of a subsequently presented target stimulus is analyzed. To show an effect of the prime, the relation or *congruency* between prime and target concerning a particular attribute like the afforded response is manipulated. In response priming, a prime is called congruent when it is associated with the same response as the target. Accordingly, a prime is called incongruent when it affords a different response as the target. When there is a difference in performance between congruent primes and incongruent primes, this shows that the primes must have had an impact on the processing of or responding to the target. Typically, performance is improved, that is, responses are faster and more accurate, when the prime is congruent than when the prime is incongruent (Dehaene et al, 1998; Neumann & Klotz 1994; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzach, 2003). This difference in performance is called the congruency effect and indicates an influence of unconsciously presented stimuli.

A huge advantage of the masked priming paradigm compared to the aforementioned methods is that it allows for a relatively good control of all variables, especially concerning the crucial prime visibility. The primes are presented unconsciously both due to a very short stimulus duration (e.g., 20 to 30 ms) and the use of a mask that prevents the conscious perception of the

stimulus. There are different kinds of masking techniques, the two most common being metacontrast masking and pattern masking (Breitmeyer & Ögmen, 2006; Kinsbourne & Warrington, 1962). In metacontrast masking, the prime is rendered invisible by a following stimulus (often the target stimulus itself) whose inner contours enclose the outer contours of the prime (Breitmeyer, 1984), which prevents a conscious perception of the prime. In pattern masking, the prime is followed (and oftentimes also preceded) by a pattern mask consisting of irrelevant stimuli like strings of letters or random pixels. Again, the (near) immediate presentation of new visual input prevents a conscious representation of the masked stimulus. Without going into too much detail why that is the case, it is assumed that when a new stimulus is seen, its information is projected rapidly in a fast forward sweep from the primary visual cortex to extrastriate streams and within 100 ms up to the motor cortex (Lamme & Roelfsema, 2000). Then, feedback connections begin to send information back from higher level areas to the earlier stages (Salin & Bullier, 1995). This feedback processing is called recurrent processing, and it is thought to play a central role for conscious experience (Lamme, 2000). While feedforward activation alone is not sufficient to give rise to conscious experience, it is the combination of the forwarded information and the recurrent information that is necessary for a stable, conscious representation of a stimulus. Now, in masked priming, the prime information is rapidly forwarded (and thus allows the prime to impact on motor processes), but when the information is recurred, the information that is now forwarded is already that of the pattern mask. As the recurrent processing does not match the forward processing, no conscious experience concerning the prime arises.

Typically, the visibility of the prime in a masked priming paradigm is measured objectively in a separate visibility test that follows the main experiment. Here, participants are alerted to the presence of the primes and have to respond to the prime instead of the target. Oftentimes, the responses are analyzed to calculate the sensitivity index d' . When the participants' performance is at chance level (i.e., d' is not different from zero), this indicates that they were not able to discriminate the primes.

In this dissertation, I will illustrate how the masked priming paradigm was adapted and advanced to study not only unconscious processing, but also its interplay with cognitive control processes. To this end, I will first give a brief overview of potential mechanisms of masked priming. I will then highlight hitherto findings concerning both the impact of top-down control on unconscious processing, and the impact of unconsciously presented stimuli on cognitive control. As the main part of this work, I will present my own experimental studies on this subject, and finally discuss the overall implications of my results for theories of automaticity and control as well as possible future research directions in this field of experimental psychology.

2. Mechanisms of masked priming

In this section, I will give an overview of the mechanisms that are assumed to be involved in masked priming. I will start with low level perceptual processes, and then illustrate different accounts of the mechanisms underlying the priming of motor response processes.

2.1 Perceptual processes

Masked primes are able to facilitate the perception and thus the processing of the target stimulus by means of perceptual similarity between prime and target. When the prime contains features of the target, like the shape or the color, this facilitates the sensory processing of the target and thus leads to faster responses in comparison to when the prime does not resemble the target in these aspects. Evidence for such perceptual priming processes can be found when comparing the effects of primes that are identical to the target (and consequently also congruent) with the effects of primes that are congruent but not identical to the target. For example, Mattler (2006) used four different stimuli both as primes and target, with two stimuli mapped to each response. To show priming effects beyond perceptual priming, Mattler analyzed RTs for prime-target pairs that were incongruent, congruent but not identical, and identical. He observed that responses after identical primes were not only significantly faster compared to incongruent primes, but also compared to congruent but not identical primes. Bodner and Dypvik (2005) observed similar results in a number judgement task (odd vs. even): When prime and target numbers were identical, this led to faster responses than congruent but not identical prime-target-pairs (e.g., 6 and 8). Further evidence that these effects are due to the sensory similarity of prime and target, and not due to higher conceptual similarity, comes from findings regarding

primes that are annotated either in the same way or in a different way than the target. Responses to prime-target-pairs that are conceptually similar, but perceptually different (e.g., the number word “one” and the digit “1”) are slower than when prime and target are in fact identical (Koechlin, Naccache, Block, & Dehaene, 1999).

To conclude, perceptual similarity between prime and target leads to priming effects that are due to the facilitation of sensory processing of the target. This low-level priming mechanism has to be kept in mind when analyzing which particular process can be impacted on by masked primes. It is important to exclude the possibility that any found effects are not due to an impact on the investigated process at hand, but are actually due to perceptually facilitated target processing (see the introduction to Experiment 6 for a discussion of such an instance).

2.2 Priming of motor processes

Masked primes have been found to be able to activate motor processes. One of the most convincing findings that demonstrates that response congruency effects can in fact be ascribed to motor activation comes from the analysis of lateralized readiness potentials (LRPs). The LRP is an event-related brain potential that reflects the preparation of motor activity on one side of the body. It thus occurs before motions like the movement of one arm or finger. Dehaene and colleagues (1998) found that masked primes triggered LRP according to their associated response, which indicates an activation of the response on a motor level. While it is widely recognized that unconsciously presented stimuli are able to impact on our motor behavior, the underlying mechanisms of this impact are still debated. Basically, the different approaches differ in the possible depth of

processing of masked stimuli. On the lower part of this depth of processing spectrum are accounts that assume masked primes are only able to activate simple stimulus-response (S-R) links that have been acquired throughout an experiment (Damian, 2001; Eimer & Schlaghecken, 1998; Neumann & Klotz, 1994). On the higher part of the spectrum are models of semantic activation, which assume that even masked stimuli can be processed up to a level of semantic analysis (Dehaene et al., 1998; Dell'Acqua & Grainger, 1999). A kind of intermediate account in this respect is the action trigger account, which features both semantic mechanisms (that work offline) and perceptual response activation (Kunde, Kiesel, & Hoffmann, 2003). I will describe these accounts briefly, as an understanding of the potential mechanisms of unconscious motor priming constitutes a starting point for the evaluation of unconscious priming of other processes, especially regarding why an impact was found or not found, and what the possible underlying mechanisms might be.

2.2.1 Stimulus-Response activation

This account assumes that processing of masked stimuli is very limited: Only low-level perceptual features can be processed, but higher analyses like semantic value of a stimulus are not possible. Thus, an activation of a response by a masked stimulus can only be based on perceptual features of the stimulus that have been linked to a response. In particular, it is assumed that visible target stimuli are linked to their associated responses. Then when the same stimulus is encountered again, be it in visible or masked form, the response is automatically activated. Crucially, as only a perceptual analysis of the stimulus is necessary, this response activation can be induced by masked stimuli. This model is in line with memory-based theories of automaticity like the instance theory of automaticity

(Logan, 1988). Here, repeated task performances lead from algorithm-based to memory-based processing. In other words, after some practice, responses to stimuli are not any more based on conceptual judgments (e.g., is the number odd or even), but on learned S-R-episodes. This means that stimuli that have been responded to in a task, especially when their number is small, are able to activate responses in an effortless and fast manner, which is then also possible with masked stimuli.

One line of evidence for an S-R-based mechanism of unconscious priming is the finding that only primes that were also presented as targets have an effect, but primes that were never consciously presented to the participant (which I will call “novel primes”) failed to impact on behavior. S-R-links can obviously only be acquired for stimuli that one has responded to, and thus only primes to which one has already responded to when they were presented as targets should be able to activate responses. Novel primes, in contrast, are not included in any S-R-episodes and thus have no memory-based response associated with them. Response activation of novel primes therefore could only stem from conceptual judgement of the primes (note that another explanation is proposed by the action trigger account, see section 1.1.1.5), but not from S-R-learning mechanisms. The absence or presence of an effect of novel primes was therefore regarded as crucial for validity of an S-R-learning mechanism.

To specifically investigate the effect of novel primes, Damian (2001) conducted two experiments in which participants had to categorize the size of objects denoted by one of twelve different target words (small vs. large). In the first experiment, the same words were used as targets as well as primes. Here Damian observed a congruency effect, with faster responses when prime and target

belonged to the same category than when they belonged to different categories. The second experiment featured the same targets as the first experiment, but a new set of twelve different words (six congruent and six incongruent) was used for the primes. Strikingly, no congruency effect was observed with these novel primes. Damian therefore argued that congruency effects that are observed when prime and target set are identical are not due to elaborate processing of the primes, but are based on S-R-learning.

2.2.2 Semantic categorization

Accounts of semantic categorization assume that masked stimuli can be processed up to a level where they can be categorized semantically. It is proposed that masked stimuli basically undergo the same processing visible stimuli do, and accordingly activate responses (or semantic networks) based on conceptual judgments to which the task instructions are applied (Dehaene et al., 1998). One possibility to show masked priming that goes beyond S-R-learning is to demonstrate that primes activate motor responses to which they were not previously mapped. This can be achieved for example by using novel primes, or by reversing the mapping.

The latter method was used by Abrams, Klinger, and Greenwald (2002). The participants first had to categorize 50 target words as pleasant or unpleasant by responding with a left or right key press. After this practice phase, these target words were used as masked primes, while 50 new words were used as targets. Crucially, the mapping for the pleasant vs. unpleasant categorization was reversed for half the participants. Accounts of S-R-learning would predict that each prime has been associated with its response, so that words that called for a left response would still prime the left response, even if the categorization now calls for the other

response due to the reversed mapping. If the prime is actually semantically categorized, however, it should now prime the response that is mapped to its category. This was in fact the case: The primes affected responding according to their valence, not according to their practiced response.

Strong evidence for semantic categorization of masked primes comes from semantic priming, where the semantic categorization does not determine the response, but semantic similarity still facilitates responding (Carr & Dragenbach, 1990; Kiefer, 2002; Kiefer & Spitzer, 2000). In the semantic priming paradigm, the task usually is to categorize the target as a word or a non-word (lexical decision task). The primes are words that are either semantically related to the target word or not. A typical finding is that responding to a target word is facilitated when the preceding prime is semantically related to the target word compared to when the prime is not semantically related. As both types of primes are associated with the same response (as both are words, not non-words), this priming effect cannot be attributed to any kind of response activation. The predominant theory is that the prime activates the semantic network it is associated with. Processing of a target word that is associated with the same semantic network is then facilitated due to the preactivation in this network (Kiefer, 2002; Neely, 1991).

2.2.3 Action trigger account

The action trigger account postulates that participants form anticipations concerning which stimuli will be behaviorally relevant for them (Kunde et al., 2003). As these anticipated stimuli are linked to particular actions, which have to be executed when the actual stimulus is presented, they are called action triggers. When a stimulus and an action trigger match, the response that is associated with the action trigger is automatically activated. This is true both for visible and for

masked stimuli, so that this mechanism can explain how masked primes influence responding. The underlying idea of this account is that action triggers allow us to respond to stimuli that we anticipate in an efficient, resource-conserving way. These action triggers are formed both on the basis of task instructions (before the task is carried out) and on the basis of stimuli encountered during the task. For example, if the instructions states that I will have to respond to the parity of a target number, I will form action triggers that consist of odd numbers and even numbers I expect to encounter (e.g., the numbers from 1 to 9), linked to the instructed response. Then during the experiment, new action triggers are formed if stimuli for which no action triggers is yet present are perceived. It is also possible that already formed action triggers are discarded due to the fact that these stimuli were anticipated, but are not actually encountered in the experiment.

The stimuli represented in action triggers are assumed to be represented on a perceptual level. Accordingly, the match between action trigger and stimulus is only assessed on a perceptual level, not on a semantic level. This makes sense against the background that the action triggers are in the first place set up to enable fast and effortless responding without the need for semantic evaluation. In this respect, the action trigger account resembles accounts of S-R-learning, which deny a semantic analysis of masked primes. The action trigger account, however, allows for an offline semantic analysis, namely when action triggers are formed based on task instructions. Here, action triggers are set up due to memory representations of categories that are featured in the instructed task. For example, if the task is to respond to tools, action triggers are formed for all stimuli belonging to this semantic category. In the experiment, this then allows these stimuli to exert

an effect. However, this effect is then not based on an online semantic analysis, but on the (perceptual) match of stimulus and action trigger.

Overall, the action trigger account emphasizes the role of task expectancies and anticipations when determining whether unconsciously presented stimuli are effective or not.

At first glance, it seems odd that there is evidence for each of these different accounts of unconscious priming. However, this does not necessarily mean that some of these findings are wrong. Instead, this implies that different mechanisms might be applicable depending on specific task conditions that modulate how stimuli are processed and thus how priming functions. It is beyond the scope of this thesis to discuss these conditions in more detail. Here it is just important to state that priming can occur at different processing stages with different underlying mechanisms, and to consider this for the subsequent experimental paradigms.

3. Limits of unconscious processing

In this chapter, I will talk about the twofold limits of unconscious processing. On the one hand, I will discuss how the effectiveness and impact of unconscious stimuli is determined by factors like anticipations and task expectancies, currently active task sets, or expertise. In other words, this concerns the influence of top-down settings on unconscious processing. According to traditional theories of automaticity, automatic processes are assumed to be purely bottom-up driven and thus should function independently of top-down processes. In recent years, however, this view was disputed by findings that the effects of masked primes are highly dependent on top-down settings (Ansorge, 2006; Kiefer, 2007; Kiesel, Kunde, & Hoffmann, 2007; Kiesel, Kunde, Pohl, & Hoffmann, 2006; Kunde et al., 2003, 2005; Martens & Kiefer, 2009). On the other hand, I will then approach this interplay from the opposite angle and shed light on the potential impact of unconscious processing on top-down settings. While it is widely accepted that unconscious stimuli are able to impact on motor responses, any impact on higher cognitive functions is still highly debated. I will thus illustrate hitherto findings concerning which processes they are able to impact on, especially regarding their potential impact on cognitive control processes (Mattler, 2003, 2006; Lau & Passingham, 2007; van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008; van Gaal, Ridderinkhof, van den Wildenberg, & Lamme 2009).

3.1 Top-down settings

3.1.1 The influence of currently active task sets

Classical theories of automaticity like those of Posner and Snyder (1975) or Schneider and Shiffrin (1977) define automatic processes as autonomous from

top-down settings. For example, Shiffrin and Schneider (1977) note that a particular automatic processes “nearly always becomes active in response to a particular input configuration”. Applied to masked priming, this would imply that a masked stimulus (nearly) always impacts on our behavior. It was found, however, that the impact of unconsciously presented stimuli is in fact not “automatic” in this sense, but instead strongly depends on current intentions (Kiefer, 2007; Kiefer & Brendel, 2006; Martens & Kiefer, 2009). This notion is accordingly found in most theories concerning the mechanisms of subliminal priming, like the action trigger account and the attentional sensitization model.

The action trigger account, which was already described in full detail in section 2.2.3, states that only stimuli that fit current task demands are able to impact on our behavior when they are presented unconsciously (Kunde et al., 2003). Masked stimuli that are not anticipated and for which no action triggers were formed have no effect, even when the task could in principal be applied to them. For example, when only digits ranging from 3 to 7 have been encountered in a magnitude task ($< 5 >$), masked digits that are outside of this range have no effect (Kunde et al., 2003). Likewise, when very few different target stimuli from a set of potentially many different stimuli are presented, only those stimuli that are presented as targets have an effect when presented as masked primes. In an experiment in which participants had to categorize animals as small or large, only four different animals were presented as targets. Animals that were used as primes, but not as targets, did not have an effect, although they were adequate stimuli for the size categorization. Presumably, during the course of the experiment, participants learned that no other stimuli than the four different targets

are presented (visibly) and thus anticipated exactly these stimuli, rendering the other primes ineffective (Pohl et al., 2010).

The attentional sensitization model (Kiefer & Martens, 2010) addresses how semantic priming is modulated by attentional sensitization through current task sets. The model assumes that automatic processes are susceptible to top-down control by enhanced task-relevant processing and attenuated task-irrelevant processing, whereby the task relevancy is determined by the currently active task set (Kiefer, 2012; Kiefer, Adams, & Zovko, 2012). It is assumed that the sensitivity of processing pathways is modulated according to the pathways' task relevancy, so that processing of task relevant stimuli is enhanced compared to task irrelevant stimuli, regardless of the visibility of the stimuli.

This model was corroborated by a series of experiments that used induction tasks to modulate the effects of subsequent masked semantic primes. This paradigm is based on a standard semantic priming paradigm, in which a lexical decision has to be performed on a target word or non-word that is preceded by a masked prime that is either semantically related to the target or not. Semantic priming is indicated by facilitated responses when the prime is semantically related to the target word compared to when the prime is not semantically related to the target word. Crucially, before prime and target are presented in each trial, participants have to perform a task that is meant to induce the activation of a particular task set. For example, the task to respond to the shape of a letter (open vs. closed) induces a perceptual task set, while a classification of animate vs. inanimate objects induces a semantic task set. It has been shown repeatedly and for different task domains (e.g., phonological, semantic, perceptual) that the effectiveness of masked primes depends on the induced task set. For example,

semantic priming only occurred after a semantic induction task, but not after a perceptual induction task (Kiefer & Martens, 2010).

Another instance of top-down modulation of the effects of masked stimuli is the top-down contingency of masked exogenous spatial cues. Exogenous spatial cues, which typically are sudden onsets (or offsets) of stimuli in the periphery of the visual field, have been demonstrated to capture attention even when they are masked (e.g., Ansorge & Heumann, 2006; Scharlau, 2002). However, a very crucial prerequisite of this attentional capture is the match of the cues to the current task settings. In other words, the cues have to resemble task-relevant stimuli, although they are in principal not task-relevant. For example, if the target stimuli are of a particular color, only cues of that color are able to capture attention. Accordingly, this form of attentional capture is also called top-down contingent capture, as the effect depends on top-down settings. Whether this top-down contingency is not only true for exogenous cues (that are presented peripherally at possible target locations), but also for centrally presented masked arrow cues, which have been found to automatically orient attention, is the subject of Experiments 2 and 3.

3.1.2 Expertise

Expertise in a particular task leads to enhanced processing of task-specific stimuli. It was shown, for example, that expert chess players have the ability to reconstruct the position of the pieces on a chess board that was only presented briefly to them (Chase & Simon, 1973a, 1973b; de Groot, 1966, 1978). This was attributed to the ability to integrate the information presented into chunks, which are meaningful constellations of chess pieces that chess experts have acquired throughout the years of playing chess. Thus, while chess novices would have to

memorize the location of every single piece on the chess board, experts can process the presented board constellation as a whole, as the chunks represent the information already in integrated form. Thus expertise enables them to encode the presented information in a more efficient way.

A study with chess novices and chess experts by Kiesel, Kunde, Pohl, Berner, and Hoffmann (2009) investigated the limits of expertise-based processing by testing whether chess expertise even enhances the processing of stimuli that are presented unconsciously. Participants were presented with a 3x3 chess grid that featured a king in the upper left corner, in addition to either a knight or a rook as an attacker. The task was to recognize if the king is in check or not. Intriguingly, on positions where the rook checked the king, the knight did not check king, and vice versa. In order to determine a checking or non-checking configuration, one therefore has to consider both the position and the identity of the attacker. This constitutes an XOR-like task: when an attacker on a particular position affords a particular response, the same response is afforded when both the attacker and the position is different. When either the attacker or the position is different (but not both), the other response is afforded. One therefore always has to integrate both the identity and the location of the attacker. The same 3x3 chess grids were also presented as masked primes. With novices as participants, these primes had no effect. RTs were the same when the prime afforded the same response as the target than when it afforded the other response. Apparently, novices were not able to determine a checking or non-checking configuration with an unconscious stimulus, and thus the technically primed response was not facilitated. Chess experts, in contrast, responded faster when the prime afforded the same response as the target. Due to the experts' enhanced processing of these task-specific

stimuli, they were able to automatically determine a checking or non-checking position even with the unconsciously presented prime, thus facilitating the response after congruent primes. Overall, the chess expertise determined whether the masked primes could exert an effect or not.

Similar results were obtained for expert typists by Heinemann, Kiesel, Pohl, and Kunde (2010). In a six-choice reaction task, participants had to respond to the target letters S, D, F, J, K, and L by pressing the accordant key on a standard keyboard, using either the index, middle, or ring finger of the left or the right hand. The targets were preceded by masked prime letters. The results showed that when the prime letter was associated with the same finger as the target letter, responses were faster than when the prime letter was associated with another finger. Importantly, this effect was modulated by typing expertise: The finger congruency of prime and target letter only influenced the response significantly with typists, but had no significant effect with typing novices. This again showed that masked response priming is modulated by expertise.

Of course, studies that compare experts with novices suffer from being quasi experiments, as the samples are not assigned randomly to control for other factors, but participants are assigned due to the expert status. It is easily conceivable that chess experts differ from chess novices not only regarding their expertise, but also regarding other factors like age (after all, becoming an expert takes a long time), intelligence, or socioeconomic status, which are all potential confounding factors. In the following Experiment 1 (see section 5), it was investigated whether these findings can be generalized to participants drawn from the very same population.

3.2 Impact beyond motor behavior: Cognitive control processes

To what extent non-conscious perception can affect us is considered “one of the most controversial issues in psychology” (Kouider, 2007, p. 857). It is probably perceived as such a controversial issue because it touches upon fundamental concepts like “free will” and the possibly non-existent function of our consciousness. Traditionally, cognitive control processes, that is, processes that allow us to act in a flexible, intentional, and deliberate way (as opposed to a predetermined, purely stimulus-driven way), are very strongly associated with consciousness. Such a relation of control and consciousness seems so appealing due to its congruency with our introspective impression that we (represented by our consciousness) are in (cognitive) control of most of our actions. This notion has consequently also found its way into theories of control and automaticity. For example, Dehaene and Naccache proclaim that “it should be impossible for an unconscious stimulus to modify processing on a trial-by-trial basis through top-down control” (2001, p. 21). In their workspace model, they imply that routine actions do not require consciousness, but consciousness is necessary for cognitive control.

Processes that are prototypical examples of cognitive control are the endogenous orientation of attention, the deliberate inhibition of an action, switching at will between different tasks, and the adjustment of stimulus processing and subsequent behavior to account for disrupting stimuli or events in the environment. All these phenomena are quite well investigated in experimental psychology. Orienting of attention is researched intensely at least since Posner devised the spatial cueing paradigm (Posner, 1980; Jonides, 1981). Inhibition processes are investigated with paradigms in which participants are told to refrain

from reacting or to cancel the execution of a response, like in the stop signal paradigm (Logan, 1982). When participants have to apply different response mappings to stimuli and respond accordingly in the task switching paradigm (Kiesel et al., 2010; Rogers & Monsell, 1995), this is thought to be a central function of cognitive control. Processes of conflict adaptation can be investigated by analyzing the modulation of the effects of interfering stimuli in interference tasks like the Stroop task (Stroop, 1935) or priming paradigms. Only in the last few years, the role of consciousness within these paradigms slowly became a focal point of interest. In the following sections, I will highlight the current state of research in this field.

3.2.1 Inhibition processes

A defining aspect of cognitive control is the ability to act in a flexible, non-determined way to stimuli you encounter. One way to achieve this is through inhibition, which is the ability to cancel a planned or already initiated action and thus withhold responding when it is deemed not appropriate or necessary. Endogenous inhibitory control is thus a typical example of a cognitive control process and is strongly associated with consciousness (Eimer & Schlaghecken, 2003)².

Studies concerning inhibitory control usually employ a Go/NoGo or stop signal task, where participants have to refrain from responding to the target stimulus when they encounter a particular signal (Logan, 1982). In the Go/NoGo paradigm, this signal is a stimulus that appears before target presentation and

² Eimer and Schlaghecken (2003) contrast endogenous inhibitory control with exogenous inhibitory control. The latter means a form of inhibitory control that arises automatically as a consequence of (unconscious) response activation. The former is response inhibition due to task-relevant events (e.g., a stop signal), which is what inhibitory control usually refers to, and what is considered in this section.

indicates that this is a NoGo trial in which no response is afforded. In the stop signal paradigm, the signal is presented only after target presentation. The stop signal paradigm can thus be employed to investigate the ability to cancel a presumably already initiated response activation, while the Go/NoGo paradigm focuses more on the ability to inhibit responding in the first place. In either case, these paradigms test the ability to endogenously inhibit responding due to task-relevant events.

Both paradigms have been modified by masking the stimuli that signal that inhibiting a response is in order to study whether endogenous inhibitory control truly “depends on the conscious detection of task-relevant signals” (Eimer & Schlaghecken, 2003, p. 8) or can in fact be initiated without consciousness. van Gaal and colleagues (2008) investigated whether participants are able to inhibit their response when a NoGo signal is presented unconsciously. Participants were instructed to respond as fast as possible upon detecting a black circle (the Go signal), but to withhold the response when this circle is preceded by a gray dot (the NoGo signal). By varying the interval between these two stimuli, the NoGo signal was either visible or masked. Although trials featuring a masked NoGo signal were subjectively identical to Go trials, it was found that participants indeed withheld their response more often in the masked NoGo trials. Additionally, when participants did respond in masked NoGo trials, they did this slower than in Go trials. This indicated that the unconsciously presented NoGo signals lead participants to inhibit their response, which either slowed down the response or even entailed complete abortion of the response. Besides these behavioral data, electrophysiological data showed that unconscious NoGo signals gave rise to activity in lateral prefrontal areas typically associated with inhibitory control

(Falkenstein, Hoormann, & Hohnsbein, 1999; Kiefer, Marzinzik, Weisbrod, Scherg, & Spitzer, 1998). These findings were corroborated by similar studies combining both the Go/NoGo paradigm and the stop signal paradigm with masked stimuli (Hughes, Velmans, & de Fockert, 2009; van Gaal et al., 2009) that yielded comparable results. Overall, these findings suggest that inhibitory control does not depend on the conscious representation of the events or stimuli that ask for inhibitory control.

3.2.2 Orienting of attention

As was mentioned before, it is a well-established finding that exogenous orienting of attention can be induced by stimuli that participants are not aware of. Scharlau (2002) demonstrated that a stimulus that is presented at the location of a preceding masked cue is judged to have appeared earlier than another stimulus at a non-cued location. This indicates a shift of attention to the unconsciously cued location, which subsequently leads to prior entry of the following stimulus. Similar results were obtained for example by Ansorge and Heumann (2006) by analyzing validity effects of masked exogenous cues. After valid cues, that is, cues that appeared at the target location, responses were faster than after invalid cues, which appeared at the non-cued location. Such a validity effect again indicates shifts of attention to the cued location, which lead to longer response times after invalid cues due to the necessity to reorient attention before the target can be processed. Additionally, Ansorge and Neumann (2005) found that only cues that fit the current task demands by being of the same color than the target stimuli were able to capture attention. This finding is especially interesting with regards to the influence of top-down settings on the effect of unconscious stimuli. However, a more intriguing question when talking about the impact of masked stimuli on

cognitive control processes is the relation of a conscious stimulus representation and *endogenous* orienting of attention. While exogenous orienting of attention is not purely externally driven (despite the name) due to its dependency on top-down settings, endogenous orienting of attention constitutes a typical cognitive control process that is thought to be controlled deliberately. However, studies investigating this topic are few and far between. To address this issue, Experiments 4 and 5 were conducted. They both feature centrally presented cues that are normally not spatially associated and thus can be considered to elicit truly endogenous shifts of attention. As these cues are presented both visibly and masked, the results of these experiments are suited to contribute fundamentally to the issue of endogenous orienting of attention and its dependency on conscious control.

3.2.3 Task set activation

The ability to switch between different tasks is a hallmark of cognitive control and enables us to respond to stimuli depending on the task at hand and its demands. Changing affordances of the environment can thus be responded to in a flexible and adaptive way.

To investigate this cognitive control process, the task switching paradigm has been developed (Rogers & Monsell, 1995; for an overview, see Kiesel et al., 2010). In this paradigm, participants have to perform (usually two) different tasks during an experiment. For example, one task could be to judge the parity of a target number, and the other task could be to judge the magnitude of a target number. With regard to the sequence of tasks, there are thus task repetitions when the task in the current trial is the same as in the preceding trial, and task switches when the task in the current trial is different from the preceding task. A

regular finding is that performance is better (e.g., faster responses) with task repetitions than with task switches. The difference in performance between task repetitions and task switches are called *switch costs*. A basic assumption is that in order to perform a particular task, an accordant *task set* has to be adopted and activated. The term *task set*, while not precisely defined, refers to the mental representation of the task, including the stimulus-response mapping, which is necessary to be able to perform the task correctly. When I intend to execute a task, I thus have to activate the accordant task set and respond to the stimulus according to the S-R-rules implemented in the task set. One explanation for the genesis of switch costs is that when the task switches, the task set has to be switched, too. In this case, the currently active task set has to be inhibited, while the task set for the upcoming task has to be activated. This “management” of the task sets is the cognitive control mechanism that is concerned here.

In a series of experiments, Mattler investigated whether the activation of a task set can be influenced by unconsciously presented stimuli (Mattler, 2003, 2005, 2006, 2007). To this end, Mattler combined an explicit task cueing paradigm with a masked priming paradigm. In a task cueing paradigm, a task cue indicates at the beginning of each trial which task has to be performed on the next target. The task sequence is random, so that it is not known in advance which task has to be performed next. Task sets are thus activated according to the information of the task cue. Mattler (2003, Exp. 4) used square and diamond shaped stimuli as task cues that indicated a timbre task (discriminate the sound of a piano vs. the sound of a marimba) or a pitch task (high tone vs. low tone). Before the task cue, a similar diamond or square shaped stimulus that functioned as the masked prime was presented. In contrast to a regular masked priming paradigm, the prime was

not associated with the motor response, but with the task to perform. The prime could indicate the same task as the task cue, or a different task than the task cue. A difference between these two cases, Mattler reasoned, would indicate an influence of the masked stimulus on cognitive control, in the same way as a response congruency effect indicates motor activation by the prime.

Mattler indeed found that responses were faster when the prime indicated the same task as the task cue than when prime and task cue were incongruent. He took these results as the demonstration of priming of cognitive control operations. These findings were corroborated, besides the subsequent studies of Mattler (2005, 2006, 2007) by Lau and Passingham (2007), who additionally used brain imaging methods (fMRI) to support the behavioral data. In this experiment, prime and cue stimuli were very similar to those used by Mattler, but participants had to either perform a semantic task or a phonological task. This allowed Lau and Passingham to analyze whether brain areas that are specific for semantic or phonological tasks are differentially impacted on by the primes. They found that when participants were primed to do a different task than the task cue indicates, activation in the cued task-specific areas was diminished, while activity in the area associated with the primed task was heightened, which reflects the impact of the masked prime on task activation.

A critical issue with these studies is that it is not entirely clear where the impact of the prime is in fact happening, i.e., whether the priming of cognitive control processes, or mental operations, as Mattler called it, are in fact responsibly for the found congruency effects, or whether the impact is in fact happening on another level of processing, namely at an early perceptual stage. As explained in section 2.1, primes facilitate the processing of stimuli that are perceptually similar

compared to perceptually different stimuli. In the studies described, when prime and cue were congruent, they not only indicated the same task, but were also perceptually similar (e.g., both were a square). Likewise, when they were incongruent, they were perceptually different (e.g., a square and a diamond). Thus, the differences in RT can be solely due to an impact on the perceptual processing of the task cue, which happens faster after congruent than after incongruent primes. Therefore, the behavioral data of these studies are not entirely conclusive. To provide conclusive behavioral data regarding the unconscious activation of task sets, I devised a slightly different experimental approach to this research question, which will be described in section 8.

3.2.4 Conflict adaptation

In the previous section, I described how the flexible activation of task sets allows us to respond to changing task demands. Now, I will describe how cognitive control allows us to adapt to environments that are (more or less) conflict-laden, and how this process depends on consciousness.

When we experience conflict, this information is used to adjust our behavior accordingly. For example, when I encounter an irrelevant conflicting stimulus, a sensible adjustment would be to try to reduce the influence of irrelevant stimuli in the near future. Also, it would be reasonable to watch out for regularities concerning in which environment conflicts happen with which frequency, and to adjust my behavior not only according to actual conflict, but already according to the environment I am in.

The first example, adaptation to recent conflict, is well-known in experimental psychology as the Gratton effect (Gratton, Coles, & Donchin, 1992). It describes an observation in conflict paradigms like the priming paradigm or the

Erikson flanker task: congruency effects are reduced after incongruent trials compared to after congruent trials. As congruency effects indicate the size of conflict, which in turn indicates the impact of the prime (or flanker), this reflects a reduced influence of the conflicting stimulus. The cognitive control system thus adapted to the experience of recent conflict by “shielding” stimulus processing from unwanted influences. Kunde (2003) investigated whether this conflict adaptation process is contingent on the conscious representation of the (preceding) conflicting stimulus. The results showed that congruency effects in the current trial are only affected by the congruency of the previous trial when the prime in the previous trial was visible, but not when it was invisible (the visibility of the current prime interestingly made no difference). This indicates that conflict adaptation to recent conflict depends on the conscious representation of the conflict (or at least the conscious perception of the conflicting stimulus), which is also supported by similar findings in affective priming (Frings & Wentura, 2008) and semantic priming (Greenwald, Draine, & Abrams, 1996). Possibly, this contingency of conflict adaptation on conflict awareness is due to the rapid decay of unconsciously presented information and the inability to be held active long enough for such a sequential modulation (Dehaene & Naccache, 2001; Dehaene et al., 2001).

Another instance of conflict adaptation, illustrated in the second example above, is the adaptation to conflict frequency in a particular context. It was observed that congruency effects depend on context features (e.g., the background color, or the location of the target) when these context features are associated with a particular frequency of conflict (Corballis & Gratton, 2003; Crump & Milliken, 2009; Lehle & Hübner, 2008). For example, Crump and Milliken

presented color words as primes and color patches as targets that were either congruent or incongruent. There were two different target locations. Crucially, when the target appeared at one particular location, the preceding prime word was probably incongruent, and when the target appeared at the other location, the prime was probably congruent. Thus, one location is associated with a higher frequency of conflict than the other. The results showed that participants were apparently able to pick up this regularity and accordingly adjust stimulus processing: When the target appeared at the high conflict frequency location, the priming effect was smaller than when the target appeared at the low conflict frequency location. This also demonstrates a remarkable temporal flexibility of conflict adaptation, as the context information only became available after prime presentation. Again, it was investigated whether this kind of conflict adaptation depends on conscious awareness of the conflicting stimulus by varying the visibility of the prime in a similar experiment (Heinemann, Kunde, & Kiesel, 2009). Indeed, a context specific proportion congruent effect was only found when the primes were visible, but crucially not when the primes were masked. This again showed that conflict adaptation, be it in relation to recent conflict or to context-specific conflict frequency, is contingent on conscious conflict awareness.

4. Overview of the conducted experiments

In the following series of experiments, I investigated both the influence of top-down control on unconscious processing and the influence of unconscious processing on top-down control. Experiment 1 is concerned with the question whether expertise determines the extent of the impact of unconscious stimuli when other potentially confounding factors that can be found in regular studies on expertise are controlled. In Experiments 2 and 3 I investigated both whether orienting of attention can be triggered by centrally presented masked stimuli that are spatially overlearned, and whether this effect, if present, is modulated by top-down settings (like it is the case with exogenous cues). Experiments 4 and 5 then tested whether endogenous orienting of attention can be induced by masked stimuli. This was realized by the implementation of centrally presented masked cues that do not (in contrast to the cues in Experiments 2 and 3) possess an inherent spatial meaning. Additionally, the data of these two experiments were analyzed with regard to sequential effects that carry over from one trial to another and their contingency on cue visibility (both in the current and the preceding trial). Finally, in Experiments 6 and 7, I researched whether the activation of task sets, a central cognitive control process, can be triggered by masked stimuli.

5. Expertise and unconscious processing of complex stimuli

The possibilities and limits of unconscious information processing have been an issue of considerable debate over the last 15 years (cf. Van den Bussche, Van den Noortgate, & Revnvoet, 2009). Only recently have we understood that expertise with a certain stimulus domain is a crucial determinant of the capability to process stimuli without awareness. For example, expert chess players (Kiesel et al., 2009) and expert typists (Heinemann et al., 2010) process unconsciously presented information while novices' performance remains unaffected by the same unconscious stimulation. These expertise-related extensions of unconscious stimulus processing might reflect experts' access to integrated multiple-feature representations that novices lack and cannot create on the fly without awareness.

Research on expertise, however, suffers from the notorious methodical problem of relying on a quasi-experimental variable which invites all kinds of alternative interpretations in terms of subject-related confounds and self-selection problems. In other words, experts may differ from novices not only in terms of practice with a certain task or skill but in other personality traits as well, which eventually determine who becomes an expert and who does not. Ideally, to rule out such subject-related accounts one would wish to study essentially the same subjects once as experts and once as novices.

Here, we suggest such an approach, which we call "de-expertisation". We tested participants that were all experts for a certain task and stimulus domain, namely reading words. However, while we allowed some subjects to process stimuli by their expert processing routines, we intentionally de-expertised some other subjects by instructing them to process stimuli differently. Eventually, however, all participants carried out the same responses to the same stimuli.

This was accomplished by having one group of participants do a lexical decision task (word vs. non-word) on the German words “es” and “so” and the non-words “se” and “os”. These participants were able to approach the task through their word reading expertise. The other group of participants had to perform a task that asked for responses according to both the identity and the location of the vowel. Stimuli in this group were mapped onto responses in an XOR-like manner by having these participants press one button when the *e* was on the left side or the *o* was on the right side, and having them press the other button when the *o* was on the left side or the *e* was on the right side (see Figure 1a for an illustration of this mapping). This instruction demands the integration of both features, as a single feature (like the identity *e* or the location *left*) is always associated with both responses. Importantly, the mapping is the same as in the lexical task, with the stimuli “es” and “so” mapped to one response, and the stimuli “os” and “se” mapped onto the other response. Eventually, everything instead of the given instruction was absolutely the same for both groups of participants.

Before each target stimulus, a prime stimulus from the same set of stimuli masked by a random pattern mask was presented for 20 ms. If expertise truly determines if unconscious stimuli are processed, participants with the lexical task should respond faster and less error prone when the masked prime stimulus affords the same response as compared to the other response as the target (Dehaene et al., 1998), as the lexical decision directly addresses the reading domain in which the participants are highly trained in and “groups of letters are rapidly and effortlessly conjoined into integrated visual percepts”(McCandliss, Cohen, & Dehaene, 2003, p. 293). For the instructed illiterates, however, the prime should have no or considerably less impact, as they cannot use their word reading

expertise and the widely automated processes associated with word reading, but have to explicitly attend to and integrate the single features of the masked prime.

The applied design allows for a more detailed analysis of perceptual influences and response congruency effects. Each prime target pair can be classified not only regarding its response congruency, but also regarding its grade of perceptual overlap of single features. In the response incongruent prime target pairs, one feature always overlaps between prime and target while the other feature is different (e.g., the identity of the vowel is the same while the location is different with the stimuli “es” and “se”). In congruent prime target pairs, either both features overlap, or, importantly, both features are different (e.g., “os” and “se”). The latter case is especially crucial, as response congruency (congruent) goes contrary to the grade of perceptual overlap (no overlap at all) here. Comparing the effects of these primes to the effects of response incongruent primes could give an indication of the involved underlying processes. We hypothesized that for the instructed illiterates, only the low level process of perceptual overlap impacts on target processing, with no effect of response congruency. If that is the case, performance is best when both features overlap (response congruent), intermediate when one feature overlaps (response incongruent), and crucially worst when no feature overlaps, although this is a response congruent prime.

5.1 Method

5.1.1 Participants

Twenty-four students of the University of Würzburg with an average age of 22 years participated in this experiment in fulfillment of course requirements or in exchange for payment. All reported having normal or corrected-to-normal vision,

were German native speakers and were not familiar with the purpose of the experiment. An experimental session lasted approximately 60 min.

5.1.2 Apparatus and Stimuli

An IBM compatible computer with a 17 inch VGA-Display and the software package E-Prime (Schneider, Eschman, & Zuccolotto, 2002) were used for stimulus presentation and response sampling. Stimulus presentation was synchronized with the vertical retraces of a 100-Hz monitor, resulting in a refresh rate of 10 ms. Responses were executed with the index fingers of both hands.

Target set and prime set were identical and consisted of the four two-letter-combinations *es*, *so*, *se* and *os*. Both forward masks and backward masks consisted of four hash marks (####). All stimuli were presented in the centre of the screen in white Courier New font on black background. Mask stimuli were presented with a point size of 40, prime and target letters were presented with a point size of 36.

5.1.3 Design and Procedure

Each trial began with a fixation cross presented for 500 ms. The forward mask was presented for 70 ms, followed by the prime with a duration of 20 ms, and a backward mask with a duration of 70 ms. The target was presented directly after the backwards mask for 200 ms, followed by a blank screen while waiting for the response.

The 16 possible prime-target-combinations were used four times in each block, which thus consisted of 64 trials in pseudo-random order. After a practice block, participants had to perform 8 blocks with self-paced pauses between each block.

There were two different instructions that varied between subjects (see Figure 1a). Half of the participants performed a lexical decision, i.e., they had to decide whether the two letters form a German word or non-word. The possible words were *es* (German for *it*) und *so* (same as in English), and the non-words were *se* and *os*. The other half of the participants had to respond to both the location and the identity of the vowel in a mapping that resembles an XOR mapping. If the *e* was on the left side or the *o* was on the right side, they had to press one button, and, accordingly, if the *e* was on the right side or the *o* was on the left side, they had to press the other button. This means that both instructions featured the exact same mapping of stimuli to responses. Regardless of the instruction, the stimuli *es* and *so* were assigned to the same response, and the stimuli *se* and *os* were assigned to the other response. The mapping to left or right responses was balanced across participants in both groups.

At the end of the experiment, we tested prime visibility in a signal detection task. Participants were fully informed about the structure of a trial and the sequence of the presented stimuli, which was shown to them on screen. They then performed 96 trials, in which they were instructed to respond to the prime instead of the target. They were also told that accuracy is most important and to take their time to make the decision. To discourage fast responding there was an interval of 1000 ms after prime-target presentation in which participants could not respond (see Vorberg et al., 2003, for implementing such a reversed response window procedure). This was done to avoid measuring the unconscious effect of the prime on the free response choice (see Kiesel, Wagener, et al., 2006; Schlaghecken & Eimer, 2004) instead of the ability to discriminate the prime.

5.2 Results

We first analyzed RTs regarding response congruency and task.

Trials with RTs deviating more than 2.5 standard deviations from the mean RT of each participant and each condition as well as error trials were excluded from the analysis.

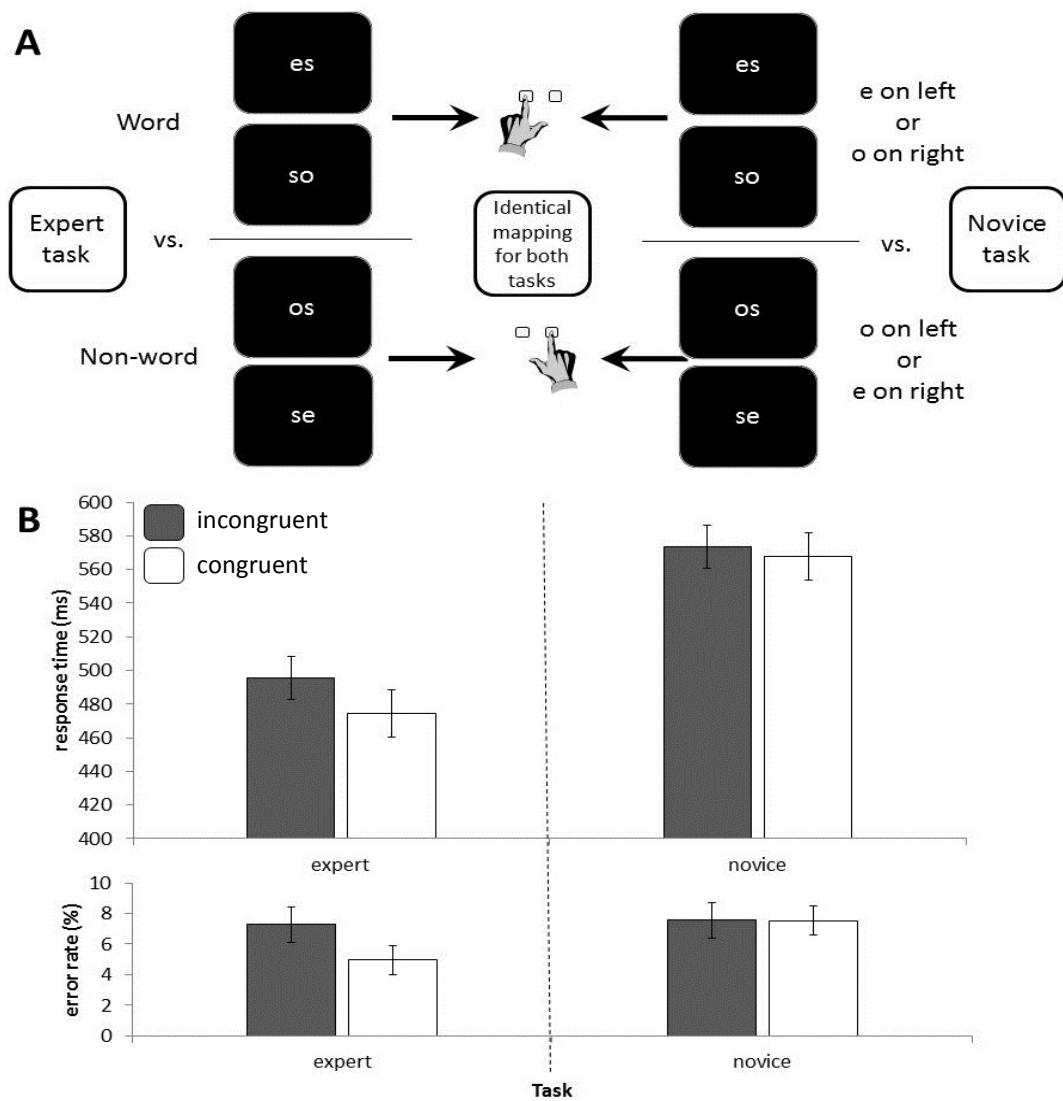


Figure 1. Panel A illustrates the mapping of stimuli to responses for both groups. While the expert task and the novice task are worded very differently, the stimulus-response mapping is identical. Panel B shows RTs and error rates as a function of response congruency and task.

Mean RTs for correct responses were submitted to a repeated measures analysis of variance (ANOVA) with the within-subject factor Congruency (response congruent vs. response incongruent) and the between-subject factor Task (expert vs. novice task). The results are illustrated in Figure 1b.

The factor Congruency was significant, $F(1, 22) = 28.404, p < .001$. Participants responded 14 ms faster when prime and target were response congruent than when they were response incongruent.

We found a significant main effect for the factor Task, $F(1, 22) = 20.827, p < .001$. Participants performing the expert task responded 84 ms faster than participants performing the novice task.

The factors Congruency and Task interacted, $F(1, 22) = 9.570, p = .005$. This interaction reflects that a significant effect of response congruency (22 ms) was only found with the expert task, $t(11) = 5.737, p < .001$, while response congruency had no significant impact on RT (5 ms) with the novice task (5 ms), $t(11) = 1.647, p = .128$.

Error rates were analyzed with the same ANOVA as RTs. A significant main effect of Congruency was observed, $F(1, 22) = 5.954, p = .037$. Participants made 1.2% less errors in response congruent than in response incongruent trials. Error rates between the expert and the novice task did not differ significantly, $F(1, 22) = 1.039, p = .319$. Additionally, we again found a significant interaction between Congruency and Task, $F(1, 22) = 4.563, p = .044$. When participants performed the expert task, they made less errors (2.3%) in response congruent trials than in incongruent trials, $t(11) = 2.641, p = .023$. When they performed novice task, however, error rates in response congruent and incongruent trials did not differ, $t(11) = 0.079, p = .938$.

To rule out that the primes remained ineffective for the novices simply because responses were slower and the primes' impact decayed, we analyzed RT distributions for congruent and incongruent trials. Congruency effects did not depend on RT level. For experts, congruency effects emerged regardless of RT and were significant even with slowest responses. In contrast, for novices, significant congruency effects were not significant throughout all RTs apart from the fastest 5% of responses.

We then analyzed the data regarding perceptual overlap between prime and target. This means that response congruency between prime and target was not considered, but instead the number of perceptual features prime and target shared (i.e., whether location of the vowel is the same/different, and whether identity of the vowel is the same/different).

Mean RTs for correct responses were submitted to a repeated measures analysis of variance (ANOVA) with the within-subject factor Perceptual Overlap (no features overlapping vs. 1 feature (location or identity of the vowel) overlapping vs. both features overlapping) and the between-subject factor Task (expert vs. novice task).

We found a significant main effect of Perceptual Overlap, $F(2, 44) = 56.189$, $p < .001$. Participants' RTs were 504 ms with both features overlapping, 536 ms with one feature overlapping, and 538 ms with both features overlapping.

The main effect of Perceptual Overlap was mediated by an interaction with Task, $F(2, 44) = 3.578$, $p = .036$. This interaction was characterized by a linear decrease in RT that corresponds with an increase in perceptual overlap in the novice task, and a non-linear relation in the expert task, in which participants were slowest with 1 perceptual overlap. In other words, the more features were

overlapping, the faster responses were when participants had to respond according to the feature combination. This suggests a strong influence of priming on a perceptual level. Such a pattern was not present, however, when participants had to respond according to the lexical status. Here, responses were fastest when both features overlapped, but remarkably still faster when no features overlapped in comparison to prime-target pairs with 1 overlapping feature. This pattern is reflected in the response congruency effect for the expert task reported above, as prime-target pairs with no feature overlap are response congruent, but prime-target pairs with 1 overlapping feature are response incongruent.

5.2.1 Prime Visibility

Prime visibility was assessed by computing the signal detection measure d' . This post-experimental signal detection test confirmed that the primes were indeed unconsciously presented in both groups ($d' = 0.12$, $p = .15$ for the “novices”, $d' = 0.13$, $p = .12$ for the “experts”).

5.3 General Discussion (Experiment 1)

Unconsciously presented stimuli impacted on behavior only when participants' task performance relied on reading expertise, enabling the prime to be unconsciously read and influence responding by means of word identity. When participants performed a novel task, the same stimuli were not unconsciously processed to a level necessary to influence responding. Conceivably, reading enabled holistic processing at the word level (McClelland & Rumelhart, 1981), whereas the novel task forced an analytical processing at the letter level. To respond correctly, participants would have to integrate the features identity of the vowel and its location, which likely requires attention and conscious stimulus

representation and can thus not be done on a masked stimulus (Treisman, 1996). We therefore hypothesized that perceptual overlap is the main influence on performance with the instructed illiterates, with little to no influence of response congruency. The data analysis showed that, in fact, effects of response congruency interact with the instructed task. An effect of response congruency was found only in the expert task, but not in the novice task. This strongly indicates that participants performing the expert task were able, through processes operating on highly trained procedures, to automatically integrate the features necessary to extract the lexical status of the prime. In contrast, no effect of response congruency could be observed in the novice task, although everything including the used stimuli and the S-R-mapping was virtually identical between the two tasks.

Additionally, the analysis of perceptual overlap showed an interaction with the instructed task. In the novice task, RTs decreased with the grade of perceptual overlap between prime and target, which indicates an influence of low-level perceptual features. In the expert task, influences of perceptual overlap were also present, but affected RTs only in addition to response congruency effects.

Overall, the data show that feature integration with masked stimuli is possible if the task and the stimulus material is strongly related to some form of expertise that enables automatic processing at a whole object level. If, however, the task does not address a domain of expertise, so that the explicit integration of separate features is necessary, response congruency of masked primes has no effect.

These findings are in line with studies comparing the effects of masked stimuli on chess experts and novices (Kiesel et al., 2009). These studies

accordingly found that the effectiveness of masked primes strongly depends on expertise. Our findings widen these results fundamentally, as we showed - by applying a strictly experimental design - that these observations are in fact due the difference in level of expertise, and not due to other potentially confounding factors.

This first experiment demonstrated that unconscious processing can strongly depend on top-down factors, in this case the participants' expertise in reading, or whether the task addressed a domain of expertise or not. It also showed that when participants could rely on their expertise, a more complex process like feature integration is possible even with unconsciously presented stimuli.

The next two experiments also concern the influence of top-down settings on unconscious processing, but additionally demonstrate that a typical mechanism of cognitive control, i.e., orienting of attention, can be likewise influenced by unconscious stimuli (Reuss, Pohl, Kiesel, & Kunde, 2011).

6. Top-down contingent capture of masked arrow cues

Our ability to focus cognitive resources on behaviorally relevant stimuli enables us to efficiently act and interact with our environment. This selection process is, amongst other things, achieved through spatial shifts of attention. These shifts of attention can happen in two ways, which both have been investigated extensively (e.g., Folk, Remington, & Johnston, 1992; Jonides, 1981; Müller & Rabbitt, 1989; Posner, 1980; Posner & Cohen, 1984; Theeuwes, 1991; Yantis & Johnson, 1990; Yantis & Jonides, 1990). On the one hand, shifts of attention can be initiated intentionally by the observer, for example because a task like a visual search task demands shifting attention to several locations in the visual field to find a target (Treisman & Gelade, 1980; Treisman, Sykes, & Gelade, 1977; Wolfe, 1994), or because we follow a sign or a cue stimulus that informs us about the likely location of a target stimulus (Posner, 1980; Posner, Snyder, & Davidson, 1980). This kind of shift of attention is often referred to as being endogenous, and is thus thought to reflect an intentional orienting of attention under internal cognitive control. On the other hand, sudden stimulus onsets, like a loud bang, or a flash of light, automatically draw our attention to them, without our intention to do so (e.g., Jonides & Yantis, 1988). This automatic capture of attention is called exogenous, which refers to the external aspect of this kind of orienting of attention.

Endogenous and exogenous shifts of attention have distinctive confining features, which were for example investigated with the spatial cuing paradigm (Posner, 1980; Posner et al., 1980). In this paradigm, a cue informs the participant about the location of the following target. Thereby, cues are either valid, that is the cue correctly informs the participant about the actual location of the target, or the

cue is invalid and signals a location where the target does not appear. The difference in response time (RT) between trials with invalid cues and trials with valid cues (the validity effect) is an indicator for shifts of attention, as this difference results from facilitated processing of the target stimulus because its location is already attended to after valid cues, and the necessity to first reorient the attention to the target location after invalid cues (Posner, 1980).

Validity effects occur even if the cue is not related to a certain response (because the participant has to respond to the identity of the target, not to its location, which is cued). Thus, the validity effect cannot be attributed to response priming. Instead it is assumed that participants orient their attention to the cued location. This assumption is further supported by neurophysiologic measures that provide evidence for the link between validity effects and orienting of attention (e.g., Ansorge & Heumann, 2006; Vossel, Thiel, & Fink, 2006).

In the spatial cuing paradigm, the nature of the cue, and how the cue affects our attentional system, can be varied. First, there are exogenous cues, which are sudden stimulus onsets, typically a change in luminance, that occur directly at the possible target location. Validity effects with exogenous cues can be observed when cue validity is 50%, so that there is no overall benefit for the participant to attend to the cued location (e.g., Folk & Remington, 1998, 1999; Posner, 1980; Remington, Folk, & McLean, 2001). Even when participants are instructed to ignore the cues, validity effects arise (Jonides, 1981). This reflects the automatic and externally driven nature of exogenous orienting of attention.

Second, there are endogenous cues that are presented centrally, for example letters or signs that indicate one of the possible target locations. For these cues, the mapping of cue to location is arbitrary. Thus, the cues have to be

interpreted first, before the participant can then shift attention according to the cues' meaning. This shift of attention is endogenously initiated by the participant and there usually needs to be a benefit for the participants to shift attention according to the instruction. In contrast to exogenous cues, cue validity typically has to be higher than 50% (e.g., 80% valid cues) in order to enable endogenous cues to lead to shifts of attention.

There are cases, however, in which centrally presented cues lead to shifts of attention even if cue validity is 50%. Some symbolic cues seem to have an automatic effect akin to that of exogenous cues. First, it was found that social cues like pointing gestures (Langton, Watt, & Bruce, 2000) or eye gaze (Driver et al., 1999; Friesen & Kingstone, 1998; Kunde, Skirde, & Weigelt, 2011; Langton & Bruce, 1999) automatically trigger orienting of attention. If, for example, eyes that gaze into one direction are centrally presented as cues, attention is oriented to the eye gaze direction even if the direction of the eye gaze is not informative with respect to the location of the target stimulus, that is, even if eye gaze validity is 50%. Second, the same was found for symbolic cues that have a very strong spatial meaning, like the words right or left, or arrows pointing in one direction (Eimer, 1997; Friesen, Ristic, & Kingstone, 2004; Gibson & Bryant, 2005; Hommel, Pratt, Colzato, & Godjin, 2001; Pratt, Radulescu, Guo, & Hommel, 2010; Tipples, 2002). Eimer (1997), for example, showed both with behavioral and with electrophysiological data that centrally presented arrow cues impact on attention even when they are not informative. It seems that seeing a conventional, overlearned symbol with a spatial meaning automatically directs one's visual attention to the location this symbol designates (Hommel et al., 2001). Consequently, it was argued that eye gaze and arrow cues trigger shifts of attention

that are truly reflexive, and not under volitional control (Stevens, West, Al-Aidroos, Weger, & Pratt, 2008). In a way, these symbolic cues automatically influence attention similar as exogenous cues automatically draw attention to them.

Exogenous cues that are masked so that they are invisible to the participant still have the power to capture attention (e.g., Ansorge & Heumann, 2006; Ansorge & Neumann, 2005; Ivanoff & Klein, 2003; Lambert, Naikar, McLachlan, & Aitken, 1999; McCormick, 1997; Mulckhuyse, Talsma, & Theeuwes, 2007; Scharlau, 2002; Scharlau & Ansorge, 2003; Scharlau & Neumann, 2003; for a review, see Mulckhuyse & Theeuwes, 2010). In one of the first studies on this subject, which also illustrates the difference between endogenous and exogenous orienting of attention, McCormick (1997) used peripheral bars that participants were either aware or unaware of as cues. Participants were instructed to not attend to the location where the cue appeared, but to the opposite location, where the target would appear in 85% of the trials. McCormick reasoned that the cue would first capture attention exogenously, but when participants were aware of the cue, they would reorient their attention endogenously away from the cue as instructed. This should result in faster RTs when the target appears at the opposite location than when the target appears at the same location as the cue. When participants were unaware of the cue, however, no endogenous reorienting should occur, and enhanced performance when the target appears at the location of the cue would demonstrate that the cues captured attention exogenously. The results indeed indicated that subliminal cues captured attention, as RTs were shorter when the target appeared at the location of the cue than when it appeared at the other location (one should note, however, that an alternative account based on inhibition of return (Klein, 2000) is also viable to explain this pattern of results). This also

shows that participants were not able to reorient their attention endogenously according to the instruction when they were unaware of the cue, which underlines the strong connection between awareness and endogenous control (Posner & Snyder, 1975). When participants were aware of the cue, they reoriented their attention and thus RTs were shorter when the target appeared at the likely location opposite of the cue than at the unlikely location.

In elaborating determinants of subliminal exogenous cuing, Ansorge and Neumann (2005) investigated if masked singleton-cues are able to draw attention to them, and further if this attentional capture is purely stimulus-driven or depends on top-down settings, i.e., whether it depends on active intentions of the participant. First, their results showed that masked cues were able to trigger shifts of attention. Participants responded faster after valid than after invalid cues, even when the cues were masked. Second, they found that attentional capture only worked when the cues' features were fitting those of the task. For example, in Experiment 2, participants had to respond to red bars, but the cues were not red, but black. The effect of the masked cues was virtually eliminated. The authors concluded that the effect of masked exogenous cues depends on the participant's intention, as governed by the task instructions. If masked cues do not match control settings which are set up according to the instruction to search for a target with certain features, the cues have no or only a very minor effect. More recently, it was shown that only task-relevant features of subliminally presented color singletons captured spatial attention, while cues that did not match top-down settings (i.e., when color was task-irrelevant) did not (Ansorge, Horstmann, & Worschech, 2010; Held, Ansorge, & Müller, 2010).

Thus, masked exogenous cuing effects seem to be restricted to top-down-contingent capture. This means that a cue captures attention only when it fits to current top-down settings of the participant, for example, when it fits to current search templates. Folk et al. (1992) demonstrated this phenomenon for unmasked cues. They showed that cues that appeared at possible target locations captured attention only when the cues shared the property used to locate the target (e.g., abrupt onset or certain color). Folk and colleagues concluded that attentional control settings are a function of behavioral goals. Events or stimuli that exhibit corresponding properties are able to capture attention. Such attentional capture is thus dependent on top-down-settings, and not per se dependent on overall cue validity. As we will argue later, however, overall cue validity can influence top-down settings and thus modulate contingent capture.

More evidence that masked singleton-cues are able to capture attention, but that this effect is contingent of top-down control settings, comes from perceptual latency priming (Scharlau, 2002; Scharlau & Ansorge, 2003; Scharlau & Neumann, 2003). When a masked cue precedes a visible target, the target is perceived as temporally leading another target stimulus, which is interpreted as facilitated processing of the target due to attentional capture of the cue. This effect, however, is absent or reduced when the cue does not have target-like shape or color (Scharlau & Ansorge, 2003).

The rationale behind our study was that overlearned spatial cues like arrows are able to orient attention automatically in a way that seems similar to that of exogenous cues, and thus masked arrow cues might be able to orient attention in the same way as masked exogenous cues do if the underlying mechanisms are comparable. Furthermore, we tested if such influences on attention do likewise

depend on top-down settings. We assumed that when cues are informative regarding the target's location, participants would more likely have the intention to use the cues to guide their attention, than when cues are not informative with regard to the target's location. To this end, we conducted two experiments that used the spatial cuing paradigm. In both experiments, participants were presented either a visible or a masked central arrow cue and then had to respond to a peripheral target. We varied the cue validity such that in Experiment 1 cues were not predictive, that is, cue validity was 50%, and participants had no incentive to prepare to use the cues. In Experiment 2, the cues were predictive with a validity of 80%, so that participants were likely to intentionally use the arrow cues and to set up according top-down settings as this benefited their performance.

6.1 Method (Experiment 2)

6.1.1 Participants

Twenty students (nine male) of the University of Wuerzburg with an average age of 25 years participated in individual sessions of approximately 50 min either in fulfillment of course requirements or payment (6 Euro). All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

6.1.2 Apparatus and Stimuli

An IBM compatible computer with a 17 inch VGA-Display and the software package E-Prime™ (Schneider et al., 2002) were used for stimulus presentation and response sampling. Stimulus presentation was synchronized with the vertical retraces of a 100-Hz monitor, resulting in a refresh rate of 10 ms. Viewing distance was approximately 60 cm. Responses were executed with the index fingers of

both hands and collected with external response keys. All stimuli were presented in black on a white background.

A central arrow extending 2.5 x 1.0 cm was used as cue, pointing either to the right or left side. The arrow was either metacontrast-masked by a larger rectangle extending 3.9 x 2.3 cm with an inner edge fitting exactly the contours of the arrow cues, or non-masked by just being underlined with a horizontal residual line of the mask extending 2.5 x 0.3 cm. Targets were the letters X or O, typed in bold Courier New font with a font size of 24 pixels, and were presented either on the right or left side, 11.3 cm horizontally away from the middle of the screen.

6.1.3 Procedure and Design

The sequence of events in a trial is depicted in Figure 2. Each trial started with a central fixation cross extending 0.7 x 0.7 cm, that was presented for 400 ms. Following the fixation cross, a central arrow cue was presented for 2 refresh cycles of the display (20 ms). After cue presentation a blank white screen was displayed for 20 ms followed either by a metacontrast mask or an underline that was presented for 120 ms in the center of the screen, followed again by a blank white screen, displayed for 40 ms. At last, the target letter was presented for 250 ms. Participants could respond within a time window of 5000 ms after target onset. After response execution a fixed time interval of 1000 ms elapsed before the next trial started. All 8 different possible combinations of cue (left/right-pointing arrow), masked/non-masked, target identity (X/O), and target side (left/right) were presented equally often, 80 times each (640 altogether), and were varied randomly on a trial-by-trial-basis. Thus, the arrow cue had a validity of 50%. After each 64 trials, participants were allowed a short, self-paced break.

Participants were informed that an arrow will appear before target onset in some of the trials, and that the arrow is pointing correctly to the side where the target letter will appear in 50% of these trials. They were instructed to look first at the fixation cross and then to respond as fast and as accurately as possible to the identity of the laterally presented target letter. Half of the participants had to press a left key when the letter O was presented and a right key when the letter X was presented. For the other half of the participants, the mapping was reversed. Errors were indicated by the German word for wrong (“Falsch!”) presented in red in the lower part of the monitor. Response times were recorded from the onset of the target stimulus until a response was given.

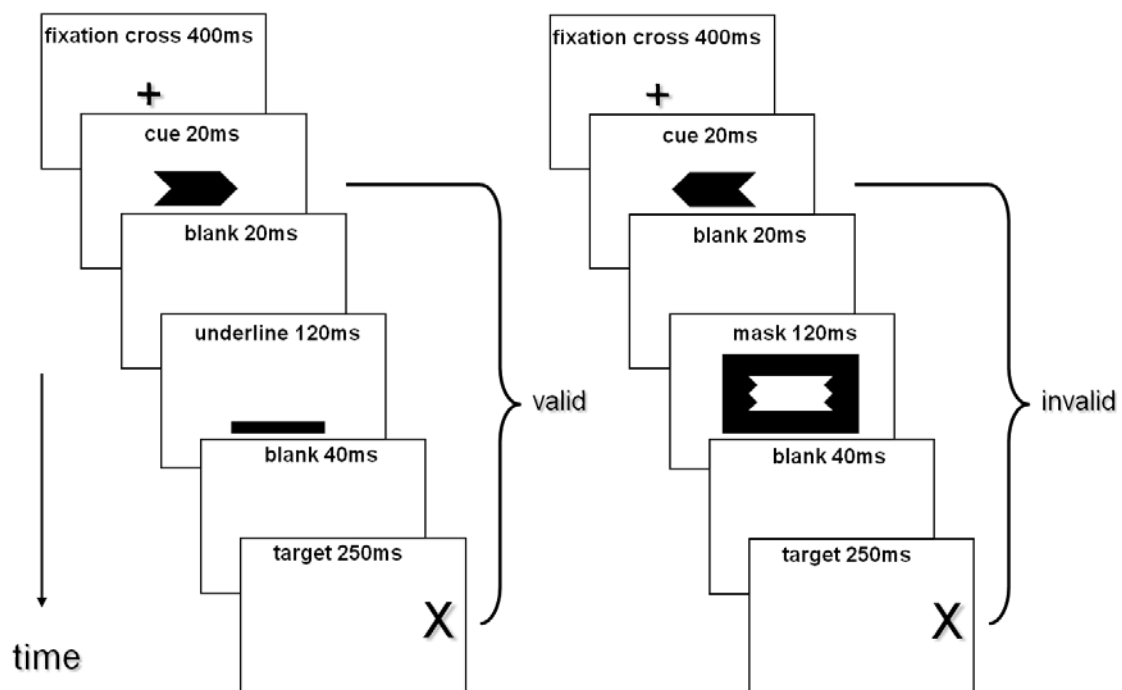


Figure 2. Sequence of stimuli in trials in Experiment 1 and Experiment 2. On the left, the sequence of stimuli in a trial with a non-masked arrow cue that is valid is illustrated. On the right, the sequence of stimuli in a trial with a masked arrow cue that is invalid is illustrated.

6.1.4 Assessment of Cue Visibility

A visibility test with additional 128 trials with non-masked and masked arrow cues was applied directly after the main experiment. Participants were fully informed about the structure of a trial and the presence of masked (und non-masked) cues. They had to perform a forced-choice discrimination task. For this task, the sequence of stimuli was exactly the same as in the main experiment. However, there was no time limit after target onset. Participants were asked to discriminate whether a right- or a left-pointing arrow was presented, and had to press either a 1 (for a left-pointing arrow) or a 0 (for a right-pointing arrow) on the number pad of the keyboard. Participants could freely choose which fingers to use for this task. Participants were instructed to take their time, to try to be as accurate as possible, and if they had not seen anything to guess at least, bearing in mind the probability for a left- or right-pointing arrow was equal. In order to avoid that unconscious priming effects influence the free response choice (Kiesel, Wagener, et al., 2006; Schlaghecken & Eimer, 2004), response keys in the cue visibility task differed compared to the main experiment and additionally there was an interval of 750 ms after target offset in which no response was possible (see Vorberg et al., 2003).

6.2 Results (Experiment 2)

6.2.1 Validity effects

Trials with RTs deviating more than 2.5 standard deviations from the mean RT of each participant and each condition were excluded (2.1 %). Mean RTs for correct responses were submitted to an analysis of variance (ANOVA) with the within-subject factors Masking (masked and non-masked cue) and Validity (valid

and invalid cue). The factor Validity was significant, $F(1, 19) = 10.2, p < .01, \eta^2 = .35$, as well as the interaction of Masking and Validity, $F(1, 19) = 7.0, p < .05, \eta^2 = .27$. The main effect of Masking was not significant, $p > .16$. Single comparisons revealed that only non-masked cues, $t(19) = 3.4, p < .01$, but not masked cues, $t(19) = 0.8, p > .93$, elicited a validity effect. Participants responded 11 ms faster to valid rather than invalid non-masked arrow cues, while for masked cues there was no difference (0 ms) in RT between responses to invalid and to valid cues (see Figure 3).

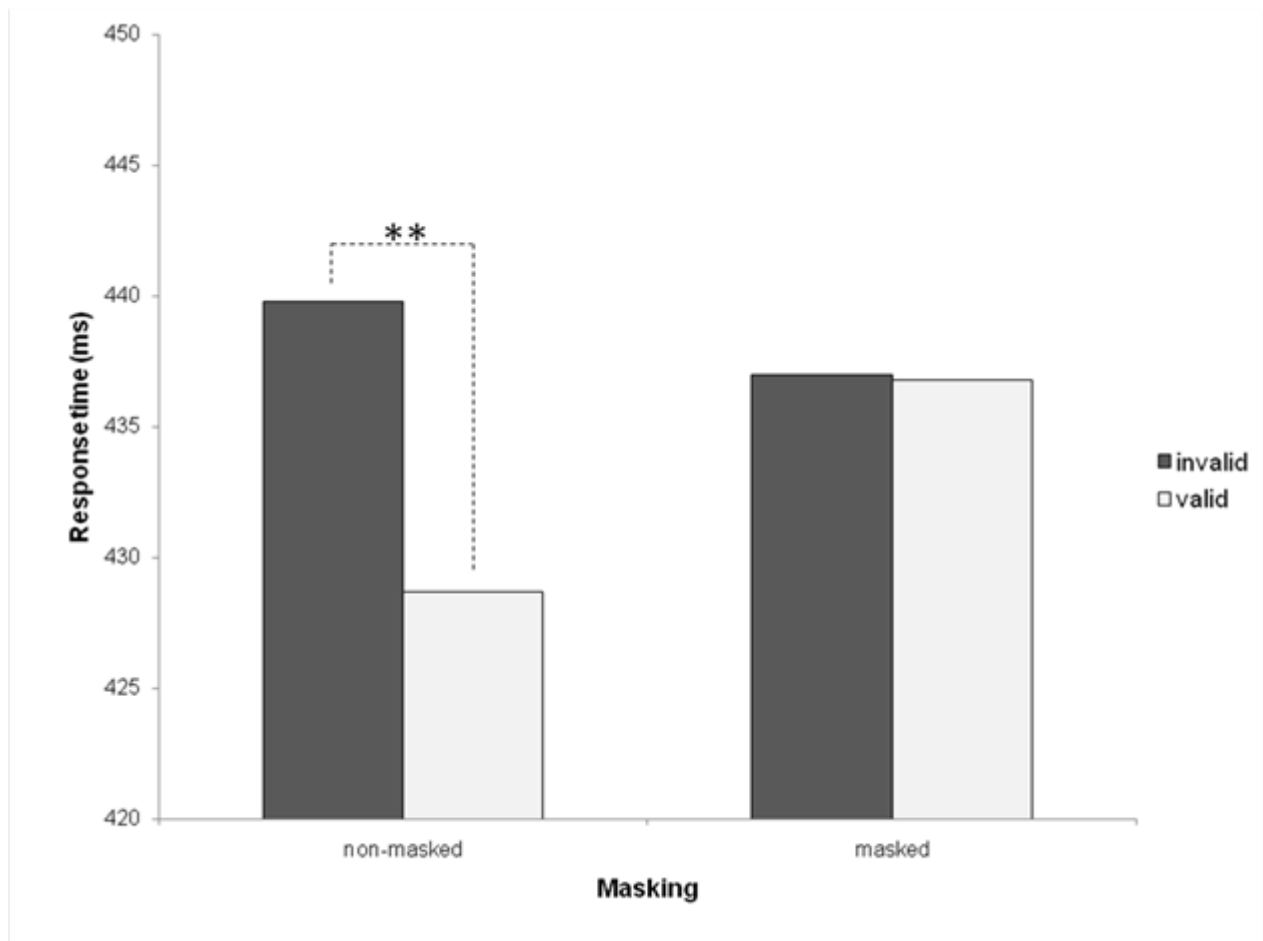


Figure 3. Response times in Experiment 2 (cue validity 50%). The dark grey bars represent RTs in trials with invalid cues, the light grey bars represent RTs in trials with valid cues. The bars in the left column depict RTs with non-masked cues, and the bars in the right column depict RTs with masked cues (** indicates effects with $p < .01$).

The overall mean error rate was 7.9%. The same ANOVA to error rates revealed no significant effects ($ps > .26$).

6.2.2 Cue Visibility

Cue visibility was assessed by computing the signal detection measure d' , separately for non-masked and masked arrow cues, treating the right-pointing arrow cue as signal and the left-pointing arrow cue as noise. Hits and false alarms proportions were corrected according to the log-linear rule if participants had 0% hits or 100% false alarms (Hautus, 1995).

Participants' discrimination performance for the non-masked cues was $d' = 3.18$, with a mean hit rate of 90.7 % and a mean false alarm rate of 9.6 %, and deviated from zero $t(19) = 12.09$, $p < .001$. Participants' discrimination performance for the masked cues was $d' = .64$, with a mean hit rate of 70.0 % (i.e., when a right pointing arrow was present), and a mean false alarm rate of 49.2 %, which deviated from zero $t(19) = 3.68$, $p < .01$. These data also show a response bias to indicate a right-pointing cue in trials with masked cues, as this response was given in 59.6% of these trials. The d' values for non-masked and masked arrow cues differed significantly from each other, $t(38) = 8.58$, $p < .001$.

6.3 Discussion (Experiment 2)

In Experiment 2, we found that centrally presented arrow cues lead to shifts of attention although they are not predictive of the target location. With non-masked cues, participants responded 11 ms faster after valid cues than after invalid cues. This validity effect reflects shifts of attention following the arrow cue, which result in facilitated target processing after valid cues, and hampered target processing after invalid cues because of the necessity to reorient attention to the

target location. This result replicates the finding that endogenous cues with a strong spatial meaning, like arrows, impact on attention akin to exogenous cues (Hommel et al., 2001; Pratt et al., 2010; Tipples, 2002).

With masked cues, however, no validity effect was found. In contrast to masked exogenous cues, masked arrow cues did not induce shifts of attention. Considering that an “overlearned symbol with a spatial meaning automatically directs one’s visual attention” (Hommel et al., 2001, p. 364), it seems rather counterintuitive that this automatic effect depends on the conscious experience of the arrow and cannot operate outside of awareness. However, it was repeatedly shown that the effects of masked exogenous cues are not purely bottom-up and stimulus-driven, but that attentional capture strongly depends on top-down control settings (e.g., Ansorge & Heumann, 2006; Ansorge & Neumann, 2005; Ivanoff & Klein, 2003; Scharlau, 2002; Scharlau & Ansorge, 2003; Scharlau & Neumann, 2003). With the experimental design of Experiment 1, participants had no incentive to orient their attention according to the cue. The cues were not predictive regarding the actual location of the target, and participants were not explicitly instructed to orient their attention according to the cue. Therefore, we conjecture that participants did not form the top-down setting, or “action plan”, to use the arrows by shifting attention to the indicated location. With visible arrow cues, the impact of the overlearned stimulus is so strong that an effect occurs exogenously without such an action plan. Masked cues, however, presumably only impact the system if it is set up accordingly.

To test this assumption, we ran Experiment 3 with an overall cue validity of 80%. With this manipulation, the arrow cues were predictive regarding the target’s

location, and participants most likely formed an action plan to use the arrow cues to shift their attention.

6.4 Method (Experiment 3)

6.4.1 Participants

Twenty students (three male) of the University of Wuerzburg with an average age of 22 years participated in individual sessions of approximately 50 min either in fulfillment of course requirements or payment (6 Euro). All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

6.4.2 Apparatus, Stimuli, Procedure and Design

Apparatus, stimuli, procedure and design were identical to Experiment 2, except for the following changes. The arrow cues had a validity of 80%, so that the target appeared in the cued location in 80% of the trials, and in the other location in 20% of the trials. All other combinations of cue (left/right-pointing arrow), presence of a mask or a line, target identity (X/O), and target side (left/right) were varied orthogonally, with the target side corresponding to the arrow in 80% of the trials. In total, there were 40 trials, of which 32 were valid and 8 were invalid trials, in a block, which was run 18 times (720 trials altogether). After each 120 trials, participants were allowed a short, self-paced break. Participants were informed that the non-masked arrow is pointing to 80% correctly to the location where the target letter will appear.

6.4.3 Assessment of Cue Visibility

Assessment of Cue Visibility was identical to Experiment 2, except that now 192 trials with non-masked and masked arrow cues were applied directly after the main experiment as visibility test. In contrast to the main experiment, the arrow cues were no longer predictive to the side where the target letter would appear, as otherwise participants were able to construe from the target's side which arrow was probably shown. Participants were informed about this.

6.5 Results (Experiment 3)

6.5.1 Validity effects

Trials with RTs deviating more than 2.5 standard deviations from the mean RT of each participant and each condition were excluded (2.1 %). Mean RTs for correct responses were submitted to an analysis of variance (ANOVA) with the within-subject factors Masking (masked and non-masked cue) and Validity (valid and invalid cue). The factor Masking was significant, $F(1, 19) = 5.1, p < .05, \eta^2 = .21$, as well as factor Validity, $F(1, 19) = 19.4, p < .001, \eta^2 = .51$. The interaction Masking Condition X Validity was not significant, $F(1, 19) = 2.4, p > .13$. Participants responded faster to non-masked (422 ms) rather than masked (426 ms) arrow cues. Single comparisons revealed a validity effect for non-masked cues, $t(19) = 3.9, p < .001$, as well as for masked cues, $t(19) = 3.1, p < .01$. Participants responded 12 ms faster to valid rather than invalid non-masked arrow cues, and 7 ms faster to valid rather than invalid masked arrow cues (see Figure 4).

The overall mean error rate was 7.0%. The same ANOVA to error rates revealed no significant effects at all ($ps > .64$).

To formally compare the results of both experiments, an additional ANOVA with the within factor Validity (valid and invalid) and the between factor Experiment (Experiment 2 with 50 % cue validity and Experiment 2 with 80 % cue validity) was conducted for RTs in both experiments for masked arrow cues only. The factor Validity was significant, $F(1, 38) = 5.3.2, p < 0.5$, as well as the interaction Validity X Experiment, $F(1, 38) = 4.8, p < .05$. This interaction reflects that the validity of the arrow cue influenced RTs in Experiment 3, while no such effect was present in Experiment 2.

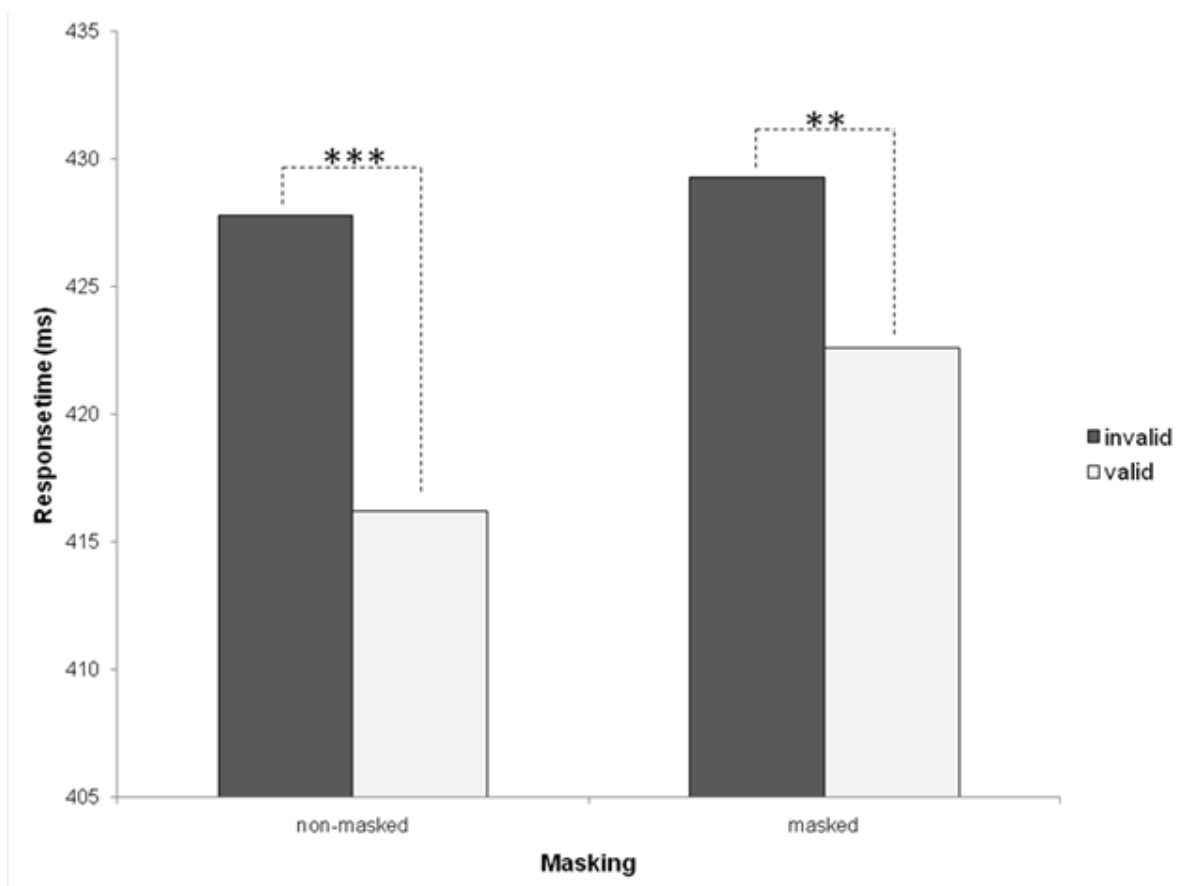


Figure 4. Response times in Experiment 3 (cue validity 80%). The dark grey bars represent RTs in trials with invalid cues, the light grey bars represent RTs in trials with valid cues. The bars in the left column depict RTs with non-masked cues, and the bars in the right column depict RTs with masked cues (** indicates effects with $p < .01$, *** indicates effects with $p < .001$).

6.5.2 Cue Visibility

Cue visibility was analyzed as in Experiment 2. Participants' discrimination performance for the non-masked cues was $d' = 3.45$, with a mean hit rate of 91.7 % and a mean false alarm rate of 8.8 %, and deviated from zero $t(19) = 11.53$, $p < .001$. Participants' discrimination performance for the masked cues was $d' = .69$, with a mean hit rate of 73.5 % and a mean false alarm rate of 51.3 %, and deviated from zero $t(19) = 3.18$, $p < .01$. These data also show a response bias to indicate a right-pointing cue in trials with masked cues, as this response was given in 62.4% of these trials. Again, as in Experiment 1, the d' values for non-masked and masked arrow cues differed significantly from each other, $t(38) = 7.44$, $p < .001$. Comparing the results for the visibility of the cues between Experiment 1 and 2, neither the d' values for non-masked cues, $t(38) = -.41$, $p > .68$, nor for masked cues, $t(38) = -.181$, $p > .86$, differed.

6.6 Discussion (Experiment 3)

In Experiment 3, participants responded faster after valid than after invalid arrow cues. In contrast to Experiment 2, this validity effect was present not only for visible, but also for masked arrow cues, and indicates that shifts of attention were triggered both by visible and masked cues. The critical difference to Experiment 2 was that cue validity was raised from 50% to 80%. With cues that are predictive of the target's location, participants are likely to form intentions to use the cues, as this benefits their performance. This intention seems to be crucial for masked cues to have an effect on attention.

When comparing the validity effects of Experiment 2 and 3, it seems surprising that the validity effect with visible cues did not increase in Experiment 3, but was virtually the same as in Experiment 1. One might expect a larger validity

effect with the additional incentive to use the cues provided by their increased validity. One reason why this was not the case might be the relatively short cue-target SOA (200 ms) used in the experiments at hand. We conjecture that endogenously driven shifts of attention emerged too slowly to be observable in the RT data. So on the one hand, the intention to use the cues enabled masked cues to automatically trigger shifts of attention that occurred rapidly and thus were observable in a validity effect. On the other hand, possible endogenously initiated shifts of attention that are due to this intention emerged too late after cue onset so that they could not effectively influence RTs and thus did not add to the size of the validity effect. As our experiments only had one fixed SOA, this hypothesis is of course speculative and would need to be corroborated (or dismissed) by similar experiments that implement different and especially longer SOAs.

6.7 General Discussion (Experiments 2 and 3)

We conducted two experiments to investigate the effect of visible and masked arrow cues on attention. We were able to replicate findings that visible, centrally presented arrows trigger automatic shifts of attention (Friesen et al., 2004; Gibson & Bryant, 2005; Hommel et al., 2001; Pratt et al., 2010; Tipples, 2002). Most importantly, masked arrow cues also triggered shifts of attention, yet only when overall cue validity was 80%, whereas masked cues remained ineffective when overall cue validity was 50%. Thus, our results showed that with masked arrows, the effect of centrally presented arrows is not purely stimulus driven, but modulated by the participants' current intentions and top-down settings.

In recent studies, arrow cues, among others like eye gaze cues (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999), have been found to have automatic effects on attention when presented centrally as spatial cues.

Usually, centrally presented spatial cues only affect attention if the observer intends to shift attention according to the cue. We conjecture that the observer endogenously controls these shifts of attention, and they are only initiated if cue validity is above chance level so that the cues benefit performance. Arrow cues, however, seem to have a more automatic effect on attention. Presumably due to their overlearned spatial meaning, attention is automatically oriented towards the indicated location by arrows, regardless of cue validity.

Such automatic capture of attention can otherwise be observed with exogenous cues that appear directly at target location. Exogenous cues even have the power to orient attention towards them when they are presented subliminally, which underlines the automatic nature of the effect (Ansorge & Heumann, 2006; Ansorge & Neumann, 2005; Ivanoff & Klein, 2003; Lambert et al., 1999; McCormick, 1997; Mulckhuyse et al., 2007). It was also found, however, that this exogenous attentional capture is not a solely stimulus driven effect, but is contingent on the cues matching the participant's top-down settings. The first aim of our experiments was therefore to test if masked arrow cues affect attention. Our second aim was to investigate if possible effects of masked arrow cues on attention are purely stimulus driven or if such effects depend on top-down settings.

In both experiments, participants had to respond to a laterally presented target by pressing one of two response keys. In each trial, an arrow cue appeared in the center of the screen. In half of the trials, however, the arrow was metacontrast-masked by a following stimulus. In Experiment 2, the arrows had a validity of 50% and so were not predictive of the target's location. With visible arrows, we found a validity effect. Participants responded faster when the arrow pointed to the location of the target than when the target appeared on the other

side. This reflects shifts of attention to the indicated location and thereby facilitated processing when the target actually appeared there, but hindered processing when attention had to be reoriented first when the target appeared on the other side. This result replicated earlier works on the effect of spatial symbols like arrows on the orienting of attention (Hommel et al., 2001; Pratt et al., 2010; Tipples, 2002).

When the arrow was masked, however, RTs were not influenced by the validity of the arrow, and thus attention was not shifted according to the arrow's direction. This result is in line with studies that investigated the effects of masked exogenous cues and observed that masked exogenous cues have to be top-down contingent, i.e., the cues' features have to somehow fit the current intentions and action plans to be able to draw attention to them (Ansorge & Heumann, 2006; Ansorge, Heumann, & Scharlau, 2002; Ansorge, Kiss, & Eimer, 2009; Ansorge & Neumann, 2005). For example, when participants in a study by Ansorge and Neumann (2005) had to respond to red stimuli, exogenous cues that were black did not draw attention while exogenous cues that were red did.

Alternatively, it is possible that participants tried to actively ignore the cues because the participants knew the cues had no actual value in helping to locate the target. With masked arrows, participants were successful with ignoring them. Non-masked arrows, however, still impact on attention and thus it seems they cannot be completely ignored successfully. This again parallels the effects of exogenous peripheral cues that also capture attention even if participants were instructed to ignore them (Jonides, 1981).

To investigate if top-down settings are crucial for the effects of masked arrow cues on attention, in Experiment 3 cue validity was raised to 80% to

encourage participants to use the arrow cues, and to form according intentions and top-down settings. With visible arrow cues, we again found a validity effect that reflects shifts of attention to the location indicated by the cue. Importantly, a validity effect was also present with masked arrow cues. Thus, in contrast to Experiment 2, attention was oriented according to the masked arrows.

As the visibility tests of both experiments did not result in different measures of sensitivity between experiments (with d' values of .64 and .69), this result cannot be attributed to differences in the visibility of the masked cues, but is due to the manipulation of cue validity and the corresponding top-down settings. In Experiment 2, participants had no incentive and thus most likely no intention to orient their attention according to the arrows (or possibly even tried to actively ignore the cues). Clearly visible arrows still had an impact on attention because of their overlearned spatial meaning, but when participants were presumably not aware of the arrow, the missing top-down settings to orient attention accordingly when an arrow is perceived was crucial and prevented the masked cues from having an effect. In Experiment 3, the incentive and the intention to use the cues was provided by the high cue validity. This top-down control setting enabled the masked arrows to impact on attention.

Remarkably, previous research that investigated if subliminally presented central arrow stimuli impact on behavior, i.e., motor responses, also comes to the conclusion that top-down settings are crucial for masked arrow stimuli to exert an effect (Eimer & Schlaghecken, 1998; Klapp, 2009; Klapp & Haas, 2005; Klapp & Hinkley, 2002; Schlaghecken & Eimer, 2004; Schlaghecken, Klapp, & Maylor, 2009). This assumption is also in line with many studies on masked priming effects that observed that subliminally presented stimuli generally impact on behavior only

if the prime fits the current top-down setting/current intentions (e.g., Ansorge, 2006; Kiefer, 2007; Kiefer & Brendel, 2006; Kiesel, 2009; Kiesel et al., 2007; Kiesel, Kunde, Pohl, & Hoffmann, 2006; Kunde et al., 2003, 2005; Martens & Kiefer, 2009; Pohl et al., 2010). Taken together, these results show that the effects of masked stimuli both on behavior and on attention are based on strikingly similar preconditions. Further research might investigate if these similarities are due to the oftentimes proposed close link between attention and the motor system (e.g., Rizzolatti, Riggio, Dascola, & Umiltà, 1987), or if this is a basic mechanism of unconscious processing that also applies to the priming of other processes besides motor or attentional processes.

To conclude, we assume that the underlying mechanisms how masked arrows induce spatial shifts of attention are comparable to how masked exogenous cues trigger shifts of attention. Both have effects on attention that seem automatic in nature. These effects, however, are not purely stimulus driven, but depend on current top-down settings.

In line with the findings of Experiment 1 that demonstrated an influence of expertise on the processing of unconscious stimuli, Experiments 2 and 3 showed a decided influence of top-down settings on unconscious processing. Additionally, the results of Experiment 3 indicate that, given the according top-down settings, centrally presented masked stimuli are able to induce shifts of attention. However, this might only be the case when the stimuli are pre-experimentally already strongly associated with the orienting of attention, which is the case with arrow stimuli. The next two experiments were thus conducted to possibly extend these findings to “true” endogenous shifts of attention, that is, orienting of attention in

response to centrally presented cues that normally do not have a spatial meaning (Reuss, Kiesel, Kunde, & Wühr, 2012).

7. Masked symbols prompt spatial anticipation

Humans can give priority to spatial locations where behaviorally relevant stimuli occur, a process referred to as spatial attention. Such orienting of attention can happen in two different ways, either *exogenously* driven or *endogenously* controlled (e.g., Folk et al., 1992; Jonides, 1981; Müller & Rabbitt, 1989; Posner, 1980; Posner & Cohen, 1984; Theeuwes, 1991; Yantis & Johnson, 1990; Yantis & Jonides, 1990). On the one hand, exogenous orienting of attention is induced by particular events in the environment. Here, anticipation plays a role insofar as only events that are behaviorally relevant are able to capture attention. If, for example, participants search for targets that abruptly onset on a screen, cues that abruptly onset automatically capture attention (Folk et al., 1992). Interestingly, if participants anticipate particular behaviorally relevant features, cues that owe these features grab attention automatically, even if they are overall not predictive for the target location.

On the other hand, humans can deliberately orient attention to certain locations in space, or in Helmholtz's words, "it is possible, simply by a conscious and voluntary effort, to focus the attention on some definite spot in an absolutely dark and featureless field" (von Helmholtz, 1866, cited after Yantis, 1998, p. 225). Typically, such conscious efforts are suggested to the participant by some symbolic cue presented in the center of vision (Posner, 1980; Posner et al., 1980). Again, anticipation is a necessary process for such cues to work, but at a different point in time, namely after rather than before cue presentation. Only if subjects anticipate targets at the cued location will central cues leave a trace in performance. Endogenously controlled shifts of attention are only executed when the target in fact appears at the cued location more often than not and is thus

anticipated there. Perhaps anticipation of the target location is what we typically describe as cueing effects or validity effects: Faster response times (RT) to targets at validly cued compared to invalidly cued locations.

The distinction between these two forms of orienting of attention and also their dependency on awareness is nicely illustrated in a study by McCormick (1997). The cues in this experiment were peripheral bars that were either visible or masked. Critically, the target appeared at the opposite location of the cue in 85% of the trials, so that participants would anticipate the target at the non-cued location. McCormick reasoned that when a cue appeared, it would at first capture attention exogenously. However, this exogenous cue could then be used strategically by the participants to endogenously shift their attention to the opposite location, where they anticipated the target. McCormick found that with visible cues, participants were indeed reorienting their exogenously captured attention in anticipation of the target. When the cues were masked, however, performance was better when the target appeared at the location of the cue. This indicates that the masked cues were able to exogenously capture attention, but that the participants were not able to voluntarily reorient their attention when the cue was masked. Subsequent work has confirmed many times that masked cues trigger exogenous shifts of attention (Ansorge & Heumann, 2006; Ansorge & Neumann, 2005; Ivanoff & Klein, 2003; Lambert et al., 1999; McCormick, 1997; Mulckhuyse et al., 2007; Scharlau, 2002; Scharlau & Ansorge, 2003; Scharlau & Neumann, 2003; for a review, see Mulckhuyse & Theeuwes, 2010).

While the possibility of exogenous cues to work outside of awareness is in line with classical theories of automaticity and control (Atkinson & Shiffrin, 1968; Posner & Snyder, 1975), the more intriguing question is the relation of

endogenously controlled orienting of attention and consciousness. In recent years, a steadily growing field of research is concerned with this relation of consciousness and cognitive control processes. For example, it was shown that the activation of task sets, a typical instance of cognitive control, can be triggered unconsciously by masked task cues (Lau & Passingham, 2007; Mattler, 2006; Reuss, Kiesel, Kunde, & Hommel, 2011). Also, there are findings that inhibition, a cognitive control process that is oftentimes conceptualized as the functional opposite of attention, can be induced unconsciously. When participants were presented with masked nogo-signals or masked stop signals, they tended to respond slower than without such a signal or they even inhibited their response altogether (Hughes et al., 2009; van Gaal et al., 2008, 2009). These findings suggest that the link between consciousness and cognitive control may not be as obligatory as traditional views of consciousness and control propose. As the focusing of attention on relevant information is regarded as one of the most elementary executive functions (Smith & Jonides, 1999), insights into the role of cue awareness in this process are essential for an understanding of the functional role of consciousness and different aspects of cognitive control.

Interestingly, however, findings regarding the role of awareness and endogenously controlled shifts of attention are scarce. As noted, McCormick (1997) found that cue awareness is necessary to perform shifts of attention in direction opposite to that indicated by a peripheral cue. Note, however, that subjects in that study had to first countermand the impact of a peripheral cue before subsequently attending to a new location. It remains therefore an open question whether masked central cues would have the power to induce shifts of attention when such countermanding is not needed. In fact, Reuss, Pohl, and

colleagues (2011) found preliminary evidence for the orienting of attention by masked central cues provided attention has not already been grabbed by another event. However, this finding is preliminary due to the specific type of cues used, namely arrows (for a similar study with eye gaze cues, see Al-Janabi & Finkbeiner, 2012). Arrow cues and other stimuli such as eye gaze and hand gestures carry an overlearned spatial meaning. Most crucially, they were found to successfully capture attention even when they were not informative regarding the target location, which is in fact a hallmark of a reflexive rather than voluntary orienting of attention (Eimer, 1997; Friesen, Ristic, & Kingstone, 2004; Gibson & Bryant, 2005; Hommel et al., 2001; Pratt et al., 2010; Tipples, 2002; Stevens et al., 2008).

Given these limitations of previous research, the present study explored if symbolic cues that carry no inherent spatial meaning have the power to bias attention without cue awareness. To study this, we presented letters that indicated the locations of the target stimuli. These cue letters were presented masked or unmasked with the presence or absence of masks changing randomly from trial to trial. The primary question was if central cues were able to impact on attention at all when they are presented unconsciously.

The experimental protocol allowed us to study another debated question regarding the effects of masked stimuli, namely carry-over effects from one trial to the next trial. A well-known sequential effect is the so-called Gratton-effect, which deals with the influence of the congruency of the previous trial on the congruency effect in the current trial. Typically, congruency effects are smaller after trials with incongruent primes than after trials with congruent primes. Several studies found such carry-over effects when primes in the preceding trial were visible but not when they were invisible (Ansorge, Fuchs, Khalid, & Kunde, 2011; Frings &

Wentura, 2008; Greenwald et al., 1996; Kunde, 2003), though under certain circumstances even invisible primes might prompt such carry-over effects (van Gaal, Lamme, & Ridderinkhof, 2010). Here, we will investigate if a cue is able to impact on the next trial depending on its visibility and the visibility of the next cue. To this end, we will analyze if the size of the validity effects is modulated by these two factors. There are reasons to expect this, though the type of impact is admittedly less clearly predictable. On the one hand, one may argue that strategies from the processing of visible cues are simply transferred to masked trials (cf. Klapp & Haas, 2005). Consequently, the impact of masked cues should increase the more recent (ideally in the last trial) a visible cue had been encountered. On the other hand, one may assume that attentional orienting by visible cues is much stronger than that by masked cues (which is in fact what we found). Perhaps masked cues have a better chance to impact on performance the less attention is still influenced by a preceding visible cue. To specifically investigate if spatial anticipations are still active in the next trial, we will compare validity effects when the cued location repeats in contrast to when the cued location switches. Persisting spatial anticipations would result in larger validity effects when the cued location repeats compared to when the cued location switches.

7.1 Method (Experiment 4)

This experiment is based on the spatial cueing paradigm by Posner (1980), with centrally presented cues that indicate a lateral location, and a target display that either includes a target or consists solely of distractors. To make sure that any shifts of attention are truly endogenous, we used letters as cues which are normally not in any way pre-experimentally associated with a direction or location.

The crucial manipulation was the visibility of the cues, which were presented either visibly or backward masked. Furthermore, to investigate the temporal dynamics of the cues' possible effects on attention, the cue target stimulus-onset-asynchrony (SOA) varied from 100 to 600 ms. As it has been shown that the magnitude of validity effects can depend strongly on the cue target SOA (e.g., Posner, 1980; Shulman, Remington, & McLean, 1979), and masked priming effects are likewise susceptible to the interval between masked stimuli and target (e.g., Vorberg et al., 2003), this relatively broad range of SOAs was applied, especially regarding the novelty of this research. Finally, we analyzed sequential interactions of visible and masked cues, specifically whether masked cues are able to impact on attention in the context of a previously presented visible or masked cue.

7.1.1 Participants

Twenty-six students (five males) of the University of Würzburg with an average age of 22 years participated in the experiment in fulfillment of course requirements or payment (18 Euro). All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment. The experiment was completed in three sessions that were run on separate days. Each session lasted approximately one hour.

7.1.2 Apparatus and Stimuli

The experiment took place in a dimly lit room. An IBM compatible computer with a 17 inch VGA-Display and the software package E-Prime™ (Schneider et al., 2002) were used for stimulus presentation and response sampling. Stimulus presentation was synchronized with the vertical retraces of a 100-Hz monitor. Responses were executed with the index fingers of both hands and collected with

external response keys. All stimuli were presented in white on a black background. The letter V or H functioned as central cues, presented in Arial font with a size of 30 pixels. Diamonds and squares with an edge length of 2 cm served as targets and distractors, respectively. In each target display, either one target and one distractor, or two distractors were presented on the left and on the right side, with a distance of 5 cm to the center. In trials with masked cues, the forward mask and backward mask consisted of a random string of 4 symbols (chosen from: #, &, \$, and %), presented in Arial font with a size of 40 pixels.

7.1.3 Procedure and Design

The sequence of events in a trial is depicted in Figure 5. Each trial started with a central fixation cross extending 0.7 x 0.7 cm that was presented for 600 ms. Following the fixation cross, a forward mask was presented for 70 ms. In trials with masked cues, the cue was presented for 30 ms, followed by a backward mask that was presented for 70 ms. In trials with visible cues, the cue was presented for 100 ms, and the backward mask was omitted. The target display appeared either immediately or after an interval of 100, 200, 300, 400, 500, or 600 ms and remained for 500 ms. Participants could respond within a time window of 2000 ms after target onset. After response execution a fixed time interval of 1000 ms elapsed before the next trial started.

Participants had to perform a single choice RT task. They were instructed to respond as fast as possible by pressing the spacebar when a target was present on either the left location or the right location, and not to respond when no target was present. Errors were indicated by the German word for wrong ("Falsch!") presented in red in the lower part of the monitor. Response times were recorded from the onset of the target stimulus until a response was given.

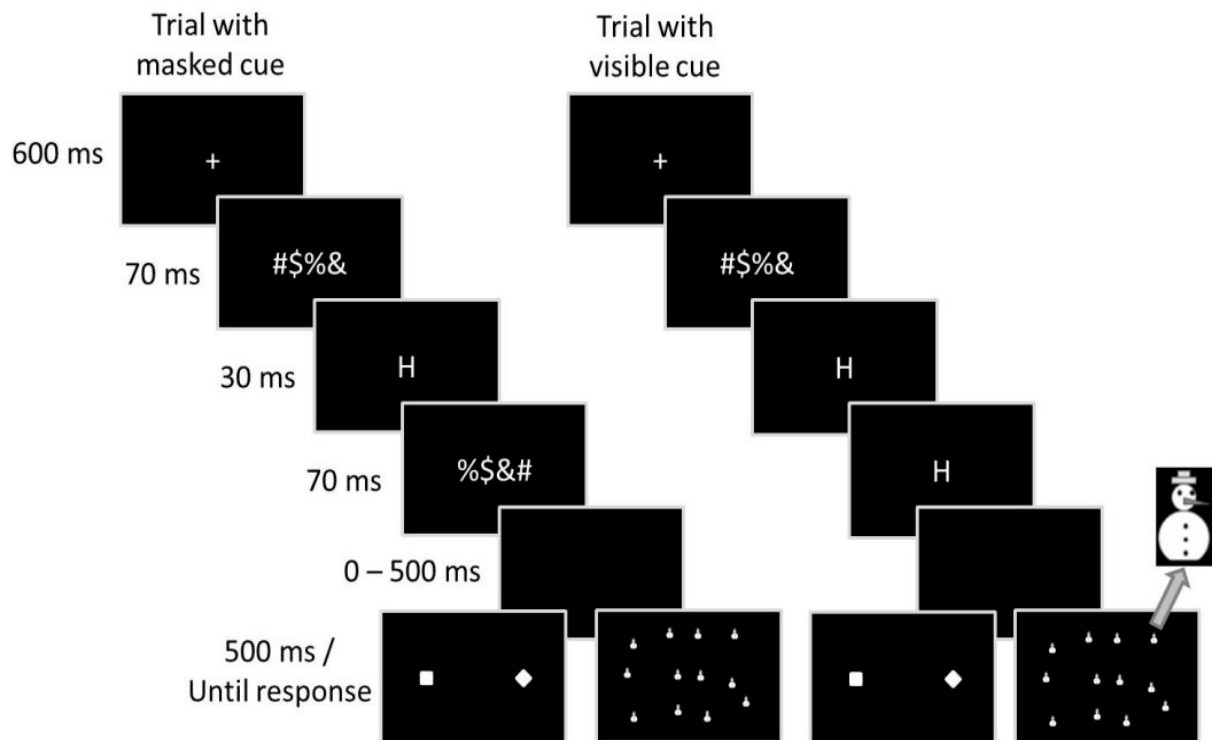


Figure 5. Sequence of stimuli in Experiments 4 and 5. On the left side, a trial with short cue duration and a backward mask is depicted. On the right side, a trial with longer cue duration and no backward mask is depicted. The lower left target display depicts the search display of Experiment 5. The other two target displays depict target displays of Experiment 4 in which a target is present.

Each block of 144 trials featured 24 catch trials in which no target was present and the participants were instructed not to respond. When a target was present, the cue indicated the location of the target correctly in 96 of these trials, i.e., with a validity of 80%. Considering all trials including catch trials, this results in an overall cue validity of 67%. During each block, each possible combination of the factors visibility of the cue, identity of the cue, location of the target, and cue-target-interval was presented once in the case of an invalid trial (24 trials), and four times in the case of a valid trial (96 trials), with the sequence of trials being randomly determined. The experiment consisted of three sessions (two sessions for the main experiment, one session for assessment of cue visibility) that took

approximately 1 hour each. Participants performed one practice block and 5 experimental blocks in the first two sessions.

Participants were informed that a visible cue, the letter *V* or *H*, will be presented in 50% of the trials, and that the cue predicted the correct location of the target in most trials. They were told not to move their eyes away from fixation when they shifted their attention. Eye movements were, however, not measured during the experiment, so that we cannot exclude the possibility of eye movements. Participants were not informed about the masked cues. The mapping of each cue to the left or to the right location was counterbalanced across participants.

7.1.4 Assessment of Cue Visibility

A visibility test consisting of 10 blocks of 72 trials each featuring both non-masked cues and masked cues constituted the third session of the experiment. Participants were fully informed about the structure of a trial and the presence of masked cues. They had to perform a forced-choice discrimination task. For this task, the sequence of stimuli was exactly the same as in the main experiment. However, there was no time limit after target onset, and the overall cue validity was lowered to 50%, so that the participants could not infer from the location of the target which cue was more likely. Participants were asked to discriminate whether a *V* or an *H* was presented, and had to press one of two response keys accordingly. Participants were instructed to take their time, to try to be as accurate as possible, and if they had not seen anything to guess, bearing in mind the probability for either cue was equal.

7.2 Results (Experiment 4)

Trials with RTs deviating more than 2.5 standard deviations (SDs) from the mean RT of each participant and each condition were excluded (1.3% of all trials). Mean RTs for correct responses were submitted to a repeated measures analysis of variance (ANOVA) with the within-subject factors cue visibility (visible cue vs. masked cue), validity (valid cue vs. invalid cue), cue-target SOA (100, 200, 300, 400, 500, and 600 ms), and previous cue visibility (visible cue vs. masked cue in trial $n-1$). The results are depicted in Figure 6.

We found significant main effects for the factors cue validity, $F(1, 25) = 12.5$, $p = .002$, cue visibility, $F(1, 25) = 6.05$, $p = .021$, and cue-target SOA, $F(1, 25) = 122.7$, $p < .001$. These main effects indicate faster responses after valid cues than after invalid cues (384 ms vs. 399 ms), faster responses after visible cues than after masked cues (388 ms vs. 395 ms), and faster responses with longer SOAs. The interaction of cue validity and cue visibility was significant, $F(1, 25) = 5.51$, $p = .027$, as well as the interaction of cue validity and cue-target SOA, $F(1, 25) = 3.58$, $p = .005$. Additionally, the three-way interaction of cue validity, cue visibility, and previous cue visibility reached significance, $F(1, 25) = 5.11$, $p = .033$. To further analyze these interactions, we conducted two separate ANOVAs for trials with visible cues and trials with masked cues.

With visible cues, we found a 25 ms effect of cue validity, $F(1, 25) = 9.28$, $p = .005$, as well as an interaction of cue validity and cue-target SOA, $F(5, 125) = 5.05$, $p < .001$, which reflects larger validity effects with longer SOAs. There was no interaction of cue validity and previous visibility, $F < 1$.

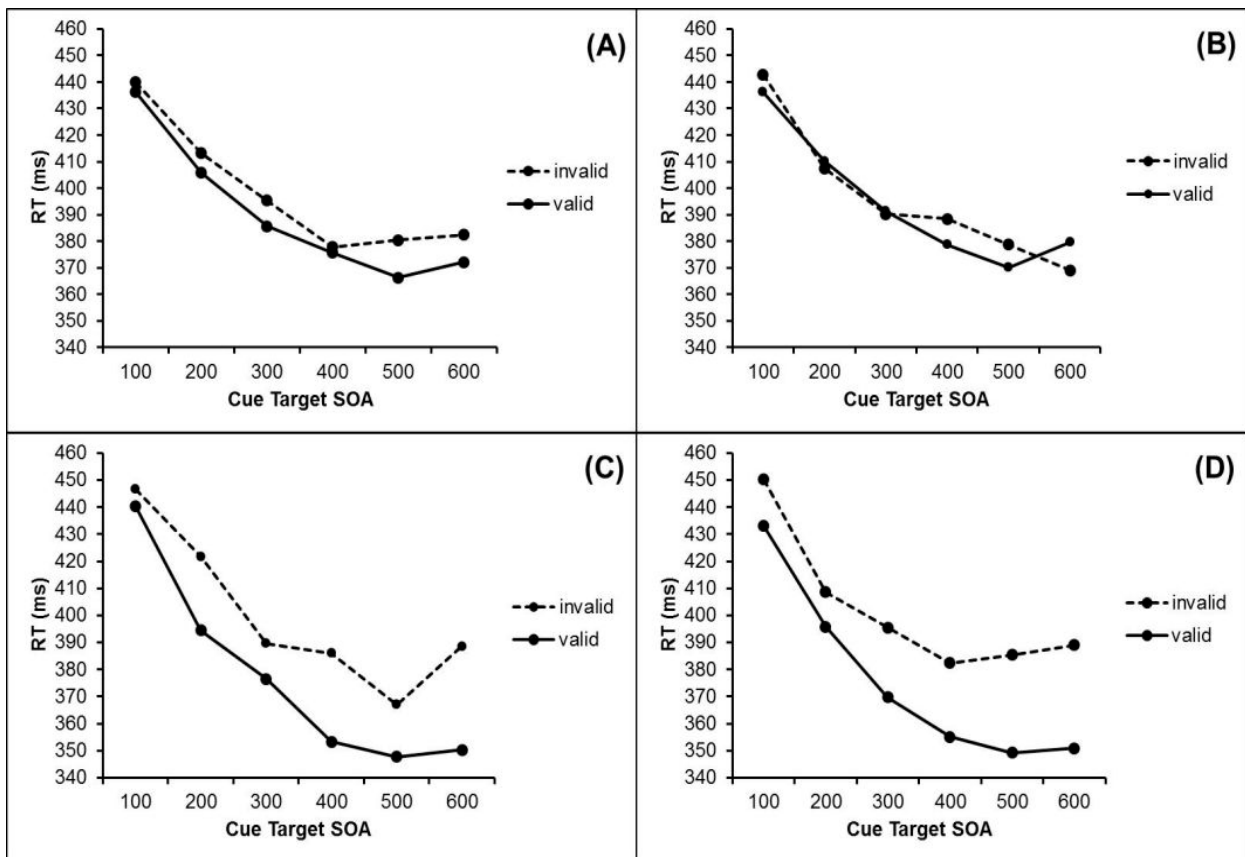


Figure 6. RTs in Experiment 4 after masked cues (upper half) and visible cues (lower half) as a function of cue validity, cue target SOA, and visibility of the previous cue. (A) RTs after masked cue when the previous cue was masked. (B) RTs after masked cues when the previous cue was visible. (C) RTs after visible cues when the previous cue was masked. (D) RTs after visible cues when the previous cue was visible.

With masked cues, there was also a significant effect of cue validity, $F(1, 25) = 4.61$, $p = .042$. Participants responded 5 ms faster after valid cues than after invalid cues. Additionally, we found a marginally significant interaction of cue validity and previous cue visibility, $F(1, 25) = 3.13$, $p = .089$. Single comparisons revealed that validity effects of masked cues were present only after trials with masked cues, $t(25) = 2.43$, $p = .023$. Here, participants responded 8 ms faster after valid cue than after invalid cues. After trials with visible cues, however, no such validity effect was found $t(25) = 0.71$, $p = .472$.

To shed light on possible underlying mechanisms of this observation, we analyzed RTs regarding cue validity (valid vs. invalid) and cued location repetition (repetition or change compared to previous trial) separately for visible and masked cues. For masked cues that follow a visible cue, we found an interaction of cue validity and previously cued location $F(1, 25) = 10.12, p = .004$. When the cued location was the same as in the previous trial, a regular validity effect of 9 ms was present. When the cued locations changed, however, the validity effect was reversed, with RTs of 392 ms after invalid cues and RTs of 397 ms after valid cues. In other words, in both cases, RTs were shorter at the previously cued location compared to the previously non-cued location. In masked trials after masked cues, a similar interaction was present, with a larger cuing effect when the cued location remained the same (9 ms) than when it changed (3 ms), but this interaction was not significant, $F(1, 25) = 1.47, p = .24$.

For visible cues that follow a visible cue, this interaction was also significant, $F(1, 25) = 8.61, p = .007$, with a larger validity effect (33 ms) when the cued location remained the same than when it changed (18ms). For visible cues that follow a masked cue the cuing effect was also a larger when the cued location remained the same (26 ms) than when it changed (20 ms), but this interaction missed significance, $F(1, 25) = 1.22, p = .279$.

Cue visibility was assessed by computing the signal detection measure d' , treating the cue V as signal and the cue H as noise. Participants' discrimination performance for the masked cues was $d' = 0.54$, with a mean hit rate of 55.7% and a mean false alarm rate of 37.8%. This value deviated from zero $t(24) = 4.64, p > .001$. To test whether any validity effects with masked cues can be ascribed to cue visibility, we assessed the relationship between each participants' individual d'

score and the effect of valid and invalid masked cues on RT. We adopted a procedure suggested by Greenwald, Klinger, and Schuh (1995; see also Draine & Greenwald, 1998; Greenwald et al., 1996) and regressed the validity effect of each participant onto individual d' scores. This analysis showed that d' scores and the effects of masked cues are not significantly correlated ($r = .283$, $p = .16$), which implies that while it cannot be definitely ruled out that some masked cues were consciously perceived, the observed effects are mostly independent of individual cue visibility and are by and large not due to conscious perception of some of the cues.

7.3 Discussion (Experiment 4)

In Experiment 4, we investigated whether centrally presented cues lead to spatial anticipations and accordant shifts of attention, and how this effect depends on the visibility of the cues, the cue target SOA, and the visibility of the previous cue. The results show that participants did form spatial anticipations based on the cues' information and shifted their attention accordingly. With visible cues, the cueing effect increased with SOA. As the interpretation of the cue and voluntarily shifting of attention takes effort and time, the benefits of correct anticipations are more pronounced when they happen before target onset.

Remarkably, masked cues also lead to the formation of spatial anticipations and accordant shifts of attention. These anticipations based on masked cues were, however, found to be more susceptible to external modulation. Specifically, masked cues were only able to impact on attention when there were no current spatial anticipations that were induced by visible information in the previous trial, i.e., masked cues were effective only when the previously presented cue was also masked, but not when it was visible.

Previously formed spatial anticipations generally had an impact on orienting of attention. Responding was faster when the target appeared at the previously cued location than when it did not. As noted above this impact of the previously cued location was stronger when the cue in the preceding trial was visible than when it was masked. In fact, when the previous cue was visible and the current cue was masked, the impact of the previous cuing seemed strong enough to override the cuing effect by a masked cue. We found that the validity effect was actually reversed when the previous cue indicated another location than the current masked cue. In this case, responses were faster with invalid cues, as this location was the one that was previously cued, and slower with valid cues, as the target then appeared at the previously non-cued location. In other words, orienting of attention was influenced stronger by the spatial anticipation formed in the previous trial than by the current masked cue. It is not entirely clear, however, whether the persisting spatial anticipation is in fact solely due to the previous cue's information, or whether it is also influenced by the previous target location. Possibly, participants tended to orient their attention towards the previous target location. Effects of the previous target location might be disentangled from effects of the previous cued location by additionally analyzing the cue validity in the previous trial. Unfortunately, the experimental design at hand does not allow for a statistically sound analysis with this additional factor, as particular factor combinations yield too few cases for each participant to perform a meaningful analysis. Thus, the distinct role of the previous target location in the sequential modulation cannot be clarified with the data at hand.

The fragility of the masked cueing effect could explain previously unsuccessful efforts to find this effect. In McCormick's study (1997), the

exogenous shift of attention triggered by the peripherally presented cue might have suppressed an effect of spatial anticipation (which would be directed on the opposite side of the screen), as an anticipation that is based on a masked cue can be influenced and possibly suppressed by other spatial information currently present.

7.4 Method (Experiment 5)

Experiment 4 showed that anticipative shifts of attention can be triggered by masked symbolic cues. To replicate and further elaborate this finding, a more demanding visual search task with a two forced choice RT task was implemented in Experiment 5 instead of the elementary target detection task of Experiment 4. To this end, Experiment 5 featured a visual search display with 11 distractors and 1 target. Here, participants had to search for one of two possible targets amongst several stimuli. The difficulty to find the target and to identify it was therefore far higher than in Experiment 4, and the benefits and costs after valid and invalid cues, respectively, were thus supposedly much larger. Like in Experiment 4, we varied the visibility of the cue and the cue target SOA. Also, we again analyze sequential effects of cue visibility.

7.4.1 Participants

Twenty-one students (thirteen males) of the University of Wuerzburg with an average age of 24 years participated in the experiment in fulfillment of course requirements or for payment (18 Euro). Informed consent was obtained from all participants. All participants reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment. The experiment was

completed in three sessions that were run on separate days. Each session lasted approximately one hour.

7.4.2 Apparatus and Stimuli

The experiment took place in a dimly lit room. An IBM compatible computer with a 17 inch VGA-Display and the software package E-Prime™ were used for stimulus presentation and response sampling. Stimulus presentation was synchronized with the vertical retraces of a 100-Hz monitor. Responses were executed with the index fingers of both hands and collected with external response keys. All stimuli were presented on a black background. Cue stimuli and masking stimuli were identical to those in Experiment 4. The target display consisted of 12 snowmen (extending 8 x 18 mm) wearing colored hats (extending 7 x 3 mm; see lower right screen of Figure 5). The snowmen were quasi-randomly distributed over the screen. For this, the screen was subdivided in 4 x 3 grids (invisible to the participants), and in each grid a snowman was presented at a random location, so that 6 snowmen were presented on locations on the left half of the screen, and 6 snowmen were presented on locations on the right side of the screen. There was always exactly 1 target snowman present, which was denoted by wearing either a blue hat or a grey hat. The other 11 distractor snowmen wore red, violet, orange, yellow, and green hats.

7.4.3 Procedure and Design

The sequence of events in a trial until the target display was identical to that of Experiment 4 (see Figure 5). The target search display was presented until a response was given, with no limitation by a response window. After response execution a fixed time interval of 1000 ms elapsed before the next trial started.

Participants had to perform a two forced choice RT task. They were instructed to respond as fast as possible to the color of the target snowman's hat. The mapping of left and right responses to grey vs. blue hats was counterbalanced across participants. Errors were indicated by the German word for wrong ("Falsch!") presented in red in the lower part of the monitor. Response times were recorded from the onset of the target stimulus until a response was given.

Participants were informed that a visible cue is presented in 50% of the trials, and that the cue indicates the correct side of the screen (left vs. right) where the target appears in most trials. They were not informed about the masked cues. The mapping of each cue to the left or to the right side of the screen was counterbalanced across participants.

Each of two experimental sessions consisted of 1 short training block (20 trials) and 9 experimental blocks of 80 trials each. All 96 possible combinations of cues, visibility of the cue, target location (left or right), cue-target SOA, and target identity (either blue or grey hat) were presented within the span of 3 blocks. All combinations with invalid cues were presented once within 3 blocks, and all combinations with valid cues were presented four times within 3 blocks. The overall cue validity was thus 80%. The experiment consisted of 3 sessions that took approximately 1 hour each.

7.4.4 Assessment of Cue Visibility

A visibility test consisting of six blocks of 96 trials featuring both non-masked cues and masked cues was applied in the third experimental session. Participants were fully informed about the structure of a trial and the presence of masked cues. They had to perform a forced-choice discrimination task. For this task, the sequence of stimuli was exactly the same as in the main experiment.

However, the overall cue validity was lowered to 50%, so that the participants could not infer from the location of the target which cue was more likely. Participants were asked to discriminate whether a V or an H was presented, and had to press one of two response keys accordingly. Participants were instructed to take their time, to try to be as accurate as possible, and if they had not seen anything to guess, bearing in mind the probability for either cue was equal.

7.5 Results (Experiment 5)

Trials with RTs deviating more than 2.5 standard deviations (SDs) from the mean RT of each participant and each condition were excluded (1.7% of all trials). RT data were submitted to a repeated measures ANOVA with the within-subject factors cue visibility (visible cue vs. masked cue), validity (valid cue vs. invalid cue), cue-target SOA (100 ms - 600 ms), and previous cue visibility (visible cue vs. masked cue in trial n-1). The results are depicted in Figure 7.

This analysis revealed a main effect of validity, $F(1, 20) = 24.2, p < .001$. Participants responded faster after valid cues (1185 ms) than after invalid cues (1327 ms). The main effect of cue visibility was also significant, $F(1, 23) = 15.8, p = .001$. Participants responded faster (1221 ms) after masked cues than after visible cues (1291 ms). The interaction of cue visibility and validity was significant, $F(1, 20) = 17.0, p = .001$, as was the three-way interaction of cue visibility, validity, and previous cue visibility, $F(1, 20) = 13.0, p = .002$. No other main effects or interactions were significant ($ps > .166$). To further investigate these interactions, we conducted two separate ANOVAs for visible and masked cues.

With visible cues, a main effect of validity revealed faster responses after valid (1164 ms) than after invalid (1440 ms) cues, $F(1, 20) = 21.2, p < .001$. The interaction of validity and previous cue visibility was significant, $F(1, 20) = 11.3,$

$p = .003$. Here, validity effects were larger after trials with visible cues (303 ms) than after trials with masked cues (217 ms).

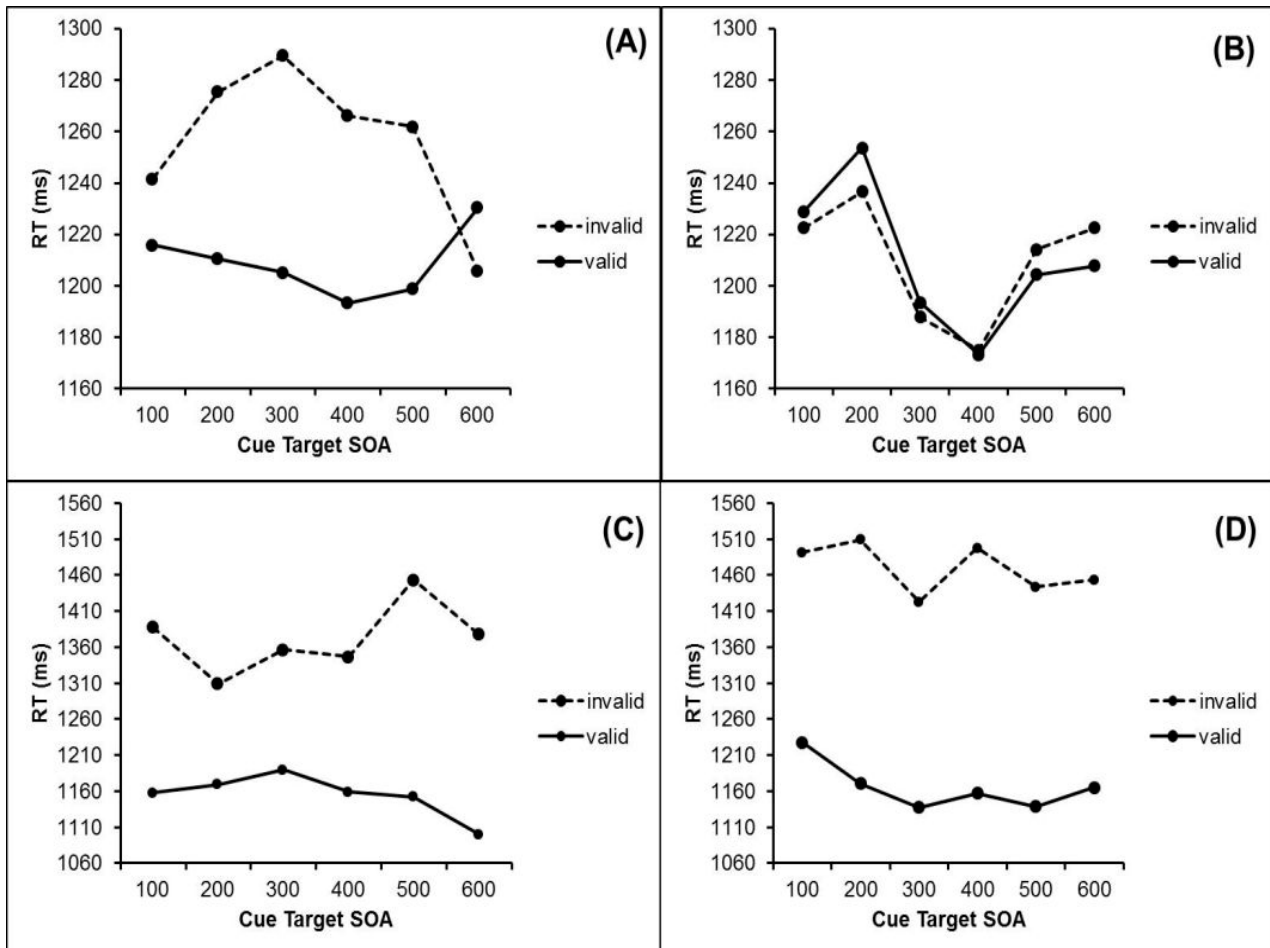


Figure 7. RTs in Experiment 5 after masked cues (upper half) and visible cues (lower half) as a function of cue validity, cue target SOA, and visibility of the previous cue. (A) RTs after masked cue when the previous cue was masked. (B) RTs after masked cues when the previous cue was visible. (C) RTs after visible cues when the previous cue was masked. (D) RTs after visible cues when the previous cue was visible.

With masked cues, we also found a significant main effect of validity, $F(1, 20) = 4.84$, $p = .04$, with responses that were 24 ms faster after valid than after invalid masked cues. The interaction of validity and previous visibility just

failed to reach marginal significance, $F(1, 20) = 2.84$, $p = .11$. In contrast to visible cues, masked cues only impacted on attention when the previous cue was also masked, $t(20) = 2.38$, $p = .027$ which is reflected in a validity effect of 48 ms. When following a visible cue, masked cues were not able to impact on attention at all, evident by an absent validity effect (0 ms).

To further understand these sequential effects we analyzed RTs regarding cue validity (valid vs. invalid) and cued location repetition (repetition or change compared to previous trial) separately for visible and masked cues. For masked cues that follow a visible cue, we found an interaction of cue validity and repetition of cued location, $F(1, 20) = 7.35$, $p = .013$. Similar to Experiment 4, there was a regular cuing effect of 72 ms when the cued locations repeated, which was reversed to a negative cuing effect (-58 ms) when the cued location changed. For masked cues that follow a masked cue, the interaction was marginally significant, $F(1, 20) = 3.27$, $p = .086$, and also reflected a regular cuing effect when the cued location repeated (77 ms) and a reversed cuing effect when the location switched (-3 ms).

For visible cues that follow a masked cue, the interaction was also significant, $F(1, 20) = 14.48$, $p = .001$, with a larger cuing effect (278 ms) when the cued location repeated than when it changed (150 ms). However, no significant interaction was found for visible cues that follow a visible cue, $F < 1$.

Cue visibility was assessed by computing the signal detection measure d' , treating the cue V as signal and the cue H as noise. Participants' discrimination performance for the masked cues was $d' = 0.186$, with a mean hit rate of 54.5% and a mean false alarm rate of 47.4%. This value deviated from zero $t(20) = 2.48$, $p = .023$. To test whether any validity effects of masked cues can be ascribed to

cue visibility, we assessed the relationship between each participants' individual d' score and the effect of valid and invalid masked cues on RT. Following a procedure suggested by Greenwald, et al. (1995; see also Draine & Greenwald, 1998; Greenwald, et al., 1996) and regressed the validity effect of each participant (RT invalid trials – RT valid trials) onto individual d' scores. This analysis showed that d' scores and the effects of masked cues were not significantly correlated ($r = .126$, $p = .596$), which implies that the observed effects are mostly independent of individual cue visibility and are by and large not due to conscious perception of some of the cues.

7.6 Discussion (Experiment 5)

The results of Experiments 5 confirmed the findings of Experiment 4 in a visual search context: Participants are able to form spatial anticipations and shift their attention accordingly on the basis of both visible and masked centrally presented cues. Participants shifted their attention to the side where they anticipated the target, which resulted in shorter RTs when the target was in fact amongst the stimuli on this side of the screen, and in longer RTs when the target was actually on the other side of the screen. With visible cues, this resulted in responses that were 276 ms faster after valid than after invalid cues. With masked cues, this effect was much smaller (24 ms) but still present. This shows that even cues that we are not aware of are able to induce spatial anticipations that lead to according shifts of attention. However, an effect of masked cues was found only when the previous trial did not contain a visible cue. This observation suggests that information provided by masked stimuli takes effect only when no stronger spatial information, i.e., that of visible stimuli, is in a still active state. The cuing effect depended on the previously cued location. It was stronger when the cued

locations repeated from previous to current trials than when they switched. As in Experiment 4, the impact of a previous visible cue was strong enough to invert the regular cuing effect from a current masked cue. Yet, even previous masked cues were able to modify cuing effects in the current trial to some degree. Within this regard, it again remains unclear whether the location of the previous target additionally influenced orienting of attention in the current trial. One exception from this overall pattern, which otherwise emerged quite consistently in both experiments, was the lack of sequence effects with two subsequent visible cues in Experiment 5. At present we have no obvious explanation for this.

The cue target SOA had less of an influence than in Experiment 4, probably because of the different time frame of the tasks. Conceivably, the information provided by the cue was not effectively used with very short cue target SOAs in Experiment 4 due to RTs that were shorter than the time needed to interpret the cue and shift one's attention. When the target display appeared shortly after the cue and probably before the shift of attention was initiated, the simple task was carried out before the accordant shift of attention was performed. With the visual search task in Experiment 5, the target display could appear before the shift of attention was initiated, but the information provided by the cue could still be effectively used because of the rather long search RTs to find the target.

7.7 General Discussion (Experiments 4 and 5)

The ability to shift our attention in anticipation of future events is an elementary process of cognitive control. Here, we provided evidence that such shifts of attention can be elicited by masked cues.

In two experiments, centrally presented letter cues informed the participants about the likely location of the upcoming target. Participants responded faster

when the target appeared at the anticipated location (i.e., after a valid cue) rather than at another location (i.e., after an invalid cue). This indicated that participants formed spatial anticipations regarding the location of the target and shifted their attention accordingly. Strikingly, this was true for visible as well as for masked cues. This is especially remarkable as the cues were deliberately chosen to be spatially arbitrary. Unlike arrows, letters possess no inherent spatial meaning. Thus, letters have to be interpreted regarding their spatial meaning to form spatial anticipations. The observed effects of the cues therefore cannot be attributed to automatically induced shifts of attention that are based on overlearned spatial relations like in previous studies (Reuss, Pohl, et al., 2011; Al-Janabi & Finkbeiner, 2012), but must be attributed to anticipatory shifts of attention generated endogenously.

In Experiment 4, participants had to recognize whether the target display contained one distractor and one target, or two distractors. With this single choice task, response times were very short. Consequently, the cue target SOA modulated the validity effect. Only with longer SOAs, the spatial information provided by the cue could be used effectively to orient attention before the target occurred and the response was given. This interaction was more pronounced in the visible cue condition. Most importantly, however, the validity effects were found both for visible and masked cues. The latter, however, were only able to impact on attention when the previous cue was also masked. This indicates that visible cues lead to strong spatial anticipations that are able to persist at least until the next trial and interfere with forming new spatial anticipations, especially those based on masked cues.

In Experiment 5, participants had to actually search for the target among eleven distractors. Thus, target detection was harder and response times were longer than in Experiment 4. The increased task difficulty worked as an incentive to use the cues, as the information provided by the cues is potentially more beneficial the harder the target is to detect, which resulted in large effects of cue validity. Also, the influence of the cue target SOA was reduced in Experiment 5 compared to Experiment 4, so that effects of cue validity were also present with very short SOAs. Besides that, the overall pattern of results was very similar to Experiment 4. Again, validity effects were found both for masked cues and visible cues, and the effects of masked cues strongly depended on the visibility of the previous cue: When the previous cue was visible, no effects of a masked cue could be observed at all. Masked cues were effective only after trials with masked cues.

To further investigate the underlying mechanism of these sequential modulations, we analyzed whether the cue information of the previous trial interacts with the current cue information depending on their respective visibility. These analyses revealed for both experiments that when the current cue was masked, participants oriented their attention towards the location that was previously cued if this previous cue was visible (and to a lesser extent also when the previous cue was masked). When the same location as in the previous trial was cued, participants responded faster when the target appeared at the cued than at the non-cued location. However, when the currently cued location differed from the cued location in the previous trial, participants responded actually faster when the target appeared at the currently non-cued location than at the currently cued location. In other words, responses were faster when the target appeared at

the location indicated by the previous visible cue compared to when the target appeared at the location that was not indicated by the previous visible cue, whereas the current masked cue had no substantial impact. This strongly suggests that spatial anticipations persist until the next trial and still influence the orienting of attention to an extent that nullifies effects of masked cues (in the case of a previous visible cue) or at least modulates their effect (in the case of a previous masked cue). It is also plausible, however, that not only the information of the previous cue, but also the actual target location in the previous trial influenced the spatial anticipation that carried over to the next trial. As the cued location is identical to the target location in the majority of trials, the observed effects can be due to either of these factors. While we analyzed whether the visibility of the previous cue influenced the observed validity effects, previous cue information is confounded with previous target location because cues were valid in most trials. Unfortunately, the present data set does not allow us to soundly disentangle the effects of both the cue information and the target location on orienting of attention in the subsequent trial, as particular factor combinations in the necessary analysis occur too infrequently to enable a meaningful analysis.

The persisting effect of already active spatial anticipations is strong enough to still impact on attention even when a visible cue is presented. However, spatial anticipations that are induced by visible cues are more resilient to such influences, so that their effect is merely modulated by already active spatial anticipations, but not completely overridden. Interestingly, this modulation took place even when the previous cue was masked.

The observation that even masked cues lead to anticipatory shifts of attention is remarkable because endogenous orienting of attention is regarded as

one of the most elementary processes of cognitive control, and cognitive control processes are traditionally associated with consciousness (e.g., Atkinson & Shiffrin, 1968; Norman & Shallice, 1986), and “authors speak of ‘conscious control’ as if there could be no alternative” (Hommel, 2007, p. 161). An effect of masked cues thus casts doubt on this proposed correlation. As outrageous as this devaluation of the functionality of our consciousness may seem, given its antagonism to our introspective impression that our conscious will controls our actions (Wegner, 2002), it is in line with recent findings concerning the relation of consciousness and other cognitive control processes like inhibitory processes (Hughes et al., 2009; van Gaal et al., 2008, 2009) and task set activation (Lau & Passingham, 2007; Mattler, 2006; Reuss, Kiesel, et al., 2011). These cognitive control processes were shown to be able to work outside of awareness.

However, one should not dismiss the differences that exist between the effects of visible cues and masked cues. First, there are quantitative differences when looking at the benefits and costs of valid cues and invalid cues depending on their visibility. The effects of visible cues are distinctively larger than those of masked cues. This indicates a stronger and more reliable impact on cognitive control processes than the one provided by masked cues. Such a quantitative difference was, for example, also found regarding the activation of task sets by masked cues (Reuss, Kiesel, et al., 2011). Second, the effects of visible cues are less prone to potential interference than the effects of masked cues. In the two experiments presented here, this is illustrated by the impact of cues on attention in the next trial. In both experiments, spatial anticipations induced by visible cues were still active in the subsequent trial. In trials with masked cues, this persisting spatial anticipation was able to strongly influence the orienting of attention,

sometimes to an extent that the current cue had no noticeable effect on attention. Visible cues were in contrast more robust against such a persisting influence. Persisting spatial anticipations were able to impact on attention in trials with visible cues as well, but the effect of visible cues was strong enough to also significantly impact on attention.

To conclude, we showed in two experiments that spatial anticipations and corresponding shifts of attention are able to be induced both by visible cues and by masked cues. This observation challenges the notion of a strong link between orienting of attention as a prototypical control process and consciousness. However, awareness of the cue still played a role regarding the reliability and robustness of the control process.

Finally, we investigated whether the activation of task sets, one of the most central cognitive control processes, can be triggered unconsciously. To corroborate earlier studies on this subject (see section 3.2.3), these experiments employed a new experimental design that allowed us to ensure that the masked stimuli in fact impacted on the cognitive control process (and not on early perceptual stages), and allowed us to investigate whether masked stimuli can induce task set activation on their own without a subsequent visible stimulus (Reuss, Kiesel, et al., 2011).

8. Unconscious activation of task sets

Even stimuli that we are not aware of can affect our behavior. This is the main message from many studies using the masked priming paradigm (Dehaene, et al., 1998; Klotz & Neumann, 1999; Kunde, 2004; Kunde et al., 2003, 2005; Vorberg et al., 2003; for reviews, see Kiesel et al., 2007; Kouider & Dehaene, 2007). In a typical masked priming paradigm, a visual target stimulus requires a speeded forced-choice response. The target is preceded by a visual prime stimulus that appears only briefly (usually about 20 to 30 ms) and it is pre- and/or post-masked by other, commonly irrelevant stimuli, or by the target itself, as with metacontrast masking (see Breitmeyer, 1984), which renders the prime essentially invisible. As the unconscious nature of the prime is crucial for interpreting results from masked priming studies, researchers commonly test whether the prime can be consciously reported, often by using a separate signal detection task.

The typical findings in masked priming studies are congruency effects: responding is faster and more accurate if prime and target are assigned to the same response (i.e., are congruent) than if they call for different responses (i.e., are incongruent). For instance, in the study of Dehaene et al. (1998), participants categorized numerals between 1 and 9 as smaller or larger than 5 by pressing one of two keys accordingly. The target number was preceded by a briefly presented and sandwich-masked prime number. Performance was better if the prime number and the target number fell into the same response category (i.e., if they were both smaller or both larger than 5) than if they did not. This (often replicated) priming effect suggests that response selection can be affected by unconscious stimulus information, presumably by priming associated responses.

Recent studies have asked whether the impact of unconscious stimuli is restricted to activating response tendencies or whether they can also affect cognitive control processes. Cognitive control processes are traditionally conceptualized as strongly related to, and depending on consciousness, in the sense that these processes require and rely on conscious decision-making and awareness (Dehaene & Naccache, 2001; Jack & Shallice, 2001; for an overview, see Hommel, 2007). These “conscious” processes of cognitive control are oftentimes contrasted against “non-conscious” automatic actions. For example, Jack and Shallice (2001) emphasize that the underlying processes engaged by conscious action are different from those engaged by automatic action. Similarly, Dehaene and Naccache (2001) claim that, while processing is possible without consciousness, consciousness is required for specific cognitive control processes.

According to this view, masked stimuli that do not reach consciousness should not be able to influence cognitive control processes. In recent years, however, this view was challenged by a number of studies (e.g., Hughes et al., 2009; Lau & Passingham, 2007; Mattler, 2003, 2005, 2006, 2007; van Gaal et al., 2008, 2009). These studies provided evidence that masked stimuli can trigger or at least affect cognitive control processes, such as the inhibition of unwanted responses (Hughes, et al., 2009; van Gaal, et al., 2008; van Gaal, et al., 2009), shifting attention (Mattler, 2003, Exp. 3; Scharlau & Ansorge, 2003), and activating task sets (Lau & Passingham, 2007; Mattler, 2003, Exp. 5; 2006, Exp. 3, 2007, Exp. 3). Especially this last observation is surprising from a conscious-control point of view, as the implementation of task sets has been considered to represent one of the most central jobs of cognitive control (e.g., Meyer & Kieras, 1999; Monsell, 1996).

The activation of task sets is commonly investigated by means of the task switching paradigm. In a task switching experiment, participants perform one of two (or more) tasks in each trial (e.g., to categorize a target number as odd or even) but occasionally are to switch to the other task (e.g., to decide whether the target number is smaller or larger than 5; see Kiesel, Kunde, & Hoffmann, 2006; Sudevan & Taylor, 1987). With the explicit task cuing procedure (Meiran, 1996) that was used in the present experiments, a task cue is presented at the beginning of each trial, informing the participant which task to perform in that trial. The common observation is that response times are elevated after a task switch, suggesting that some kind of cognitive control processes, like for example reconfiguration of the cognitive system for processing another task, has to take place (e.g., Rogers & Monsell, 1995). Given that the same stimuli require different responses in the two tasks, participants need to rewire the relevant stimulus-response mappings. It is assumed that when performing different tasks, participants adopt so-called task sets, which, as a basic definition, are a representation of the task and its S-R-mappings. When one of the possible tasks is about to be carried out, the associated task set is activated to enable the participant to perform the task. There is no generally agreed upon definition for the term task set (see, for example, Kiesel, et al., 2010; Rogers & Monsell, 1995). Within the given context, an operational definition is sufficient. Whenever participants perform a task, we assume that prior to task execution the corresponding task set was activated. There are theories that assume that a task set is not activated as a whole, but that the activation is composed of several single steps in which different aspects of the task set become activated. These

models of task set activation will be discussed in more detail later on when we discuss the results of our experiments.

Recently, Mattler (2003, 2005, 2006, 2007) reported evidence that task sets might be activated by unconscious stimulus information, suggesting that the activation of task sets might not rely on conscious decisions. However, as we will argue, this evidence is not as straightforward as it has been taken to be, so that a reevaluation is in order. In the following section, we justify this claim based on the examination of the central findings from two of Mattler's (2003, 2006) studies. As we will show, Mattler's method is likely to have invited artifacts that render strong conclusions from his observations premature. We then present results from two experiments that introduced a new methodological strategy that helps circumventing these problems.

To investigate whether masked primes can activate task sets, Mattler (2003, Exp. 5) presented masked task-set primes in a random task cuing paradigm (Meiran, 1996; Rogers & Monsell, 1995). The target stimuli were high- or low-pitched tones played by either a piano or a marimba. The two tasks required responding to either the pitch of the tone (high vs. low) or to its timbre (piano vs. marimba). Tasks were cued by presenting four stimuli at the corners of an imaginary square: three irrelevant squares and one diamond. The diamond could appear at any of the four possible positions and its horizontal location signaled the task. The task cues were fully visible but they were preceded by a briefly presented prime display. The prime display also consisted of three squares and one diamond, and the diamond could appear in either the same horizontal location as the following task cue (the congruent condition) or in another location (the incongruent condition). The four stimuli making up the prime display were slightly

smaller than the four stimuli of the cue display and fit into their shape, so to allow for metacontrast masking (Breitmeyer, 1984) of the primes by the cues. Mattler (2003) observed better performance in congruent than in incongruent trials, a finding that he took as a clear hint to subliminal priming of task sets. If a congruent prime activates the proper task set, so the idea, the participant has more time to implement the task before the onset of the target, leading to faster responses.

Even though this is a possible conclusion, there is another, presumably more plausible explanation for the observed priming effect. As described, the primes were perceptual identical to the cues, and on congruent trials the diamond appeared in both prime and cue display at the exact same location. Therefore, it is conceivable that responding in congruent trials was faster because of unconscious perceptual priming but not due to the unconscious activation of task sets. Indeed, presenting an invisible prime at the same location as a target stimulus has been demonstrated to accelerate target detection (Scharlau & Ansorge, 2003; Scharlau & Neumann, 2003), presumably because the prime already triggers the necessary shift of attention towards the target location. Likewise, unconscious primes facilitate the processing of perceptually identical targets beyond mere priming through response congruency (Bodner & Dypvik, 2005; Bodner & Masson, 2003). Given that in Mattler's (2003) study primes and targets were not only perceptually identical but also appeared at the same location, the observed priming effect may be mainly or even completely due to perceptual priming. Unfortunately, basically the same argument can be made for the related studies of Mattler (2005, 2007) and Lau and Passingham (2007), in which prime and task cue were perceptually similar in congruent trials.

Additionally to behavioral data, Lau and Passingham (2007) presented fMRI data. They used two tasks, a phonological task (judging whether the target word was bisyllabic) and semantic task (judging whether the target word referred to a concrete object), that involve spatially different brain areas. When a masked incongruent prime (i.e. a prime that indicates the other task than the target) was presented, activity in the area associated with the instructed task decreased, and activity in the brain area associated with the primed task increased. This indicates that the masked prime activated the respective task and the task set associated with it. In contrast to the behavioral data, these results cannot be explained by perceptual processes and thus, as the authors note themselves, “challenge critics to reconsider the limits of unconscious processing” (Lau & Passingham, 2007, p. 5809).

To circumvent the problem of identical primes and task cues, Mattler (2006) used two task cues for each task in a similar task switching experiment. Primes and task cues were arrows pointing left, right, up, and down. Right- and left-pointing arrows indicated the timbre task, and up- and down-pointing arrows indicated the pitch task. This resulted in three types of possible relations between prime and task cue: identical pairs, i.e. prime and task cue were the same; congruent pairs, i.e. prime and task cue were associated with the same task, but were not identical; and incongruent pairs where prime and task cue referred to different tasks. In this setting, perceptual priming by sensory similarity can be ruled out when comparing merely congruent with incongruent pairs of prime and task cue. Additionally, as only a single stimulus was presented both in the prime and the cue display, stimuli always appeared at the same location—thus ruling out an attentional advantage. In this setting, Mattler (2006) again observed an impact by

the masked primes. If the prime was associated with the same task as the cue, responses were faster and more accurate than if the prime was associated with the other task. The strongest priming effect was found when prime and cue were identical, which underlines that perceptual processes played a role in this and previous findings. But the more intriguing finding is that responding was still faster for congruent compared to incongruent prime cue pairs. Mattler took this as evidence that at least parts of the overall congruency effect indicates task set activation and is not located at perceptual or motor stages.

However, there still remains an alternative explanation for these findings that does not require any task set activation by masked primes. According to Logan and Schneider (2006; see also Schneider & Logan, 2005), cues that are assigned to the same task become part of the same ad-hoc category, so that they can prime each other. Logan and Schneider reported evidence for this assumption in an experiment that used pairs of task cues like day-night for one task and noun-verb for another task. They found a repetition priming effect when the cue in the current trial was identical to the cue in the preceding trial (e.g. day and day), and also a task repetition effect when the task repeated, but the cue differed (e.g. day and night), which suggests “a priming effect for related cues and facilitation in mediator retrieval” (Logan & Schneider, 2006, p. 1255). Applying this logic to Mattler’s (2006) study suggests that participants created one category of horizontally oriented arrows and another for vertically oriented arrows. If so, processing, say, a left-pointing cue would prime the other member of the corresponding category: the right-pointing cue. Thus, the presentation of a masked prime may lead to facilitated cue encoding of both related cues—but not to task-set priming.

The priming effect of related cues was originally meant to spread from one trial to the following trial. This means that when two cues associated with the same task are presented in consecutive trials, the first cue primes the second through residual activation in short term memory. However, the same mechanism may operate if two cues are presented consecutively in a single trial, like in the design Mattler (2006) used. The prime would thus not only prime the representation of the identical task cue but also the representation of the other task cue that is associated with the same task. Consequently, the approach to map two task cues to one task does not avoid priming of the task cue. If either of the two cues is presented to the participant after one of them was used as a prime, its encoding is facilitated due to the associative activation that took place before. Thus, the impact of the prime would again be located at an early, perceptual and categorical level but not provide conclusive evidence for unconscious task-set priming.

To see whether such conclusive evidence can be provided, we devised two experiments that took the possible methodological objections into account. We did so by dropping the prime altogether and by manipulating the visibility of the task cue itself so that participants were aware of the cue in some but not in other trials. This method did not only prevent possible artifacts arising from prime-cue interactions but it also allowed for a theoretically more interesting dependent measure: Rather than only looking whether unconscious information would speed up or slow down responding in a task switching context, as in the previous studies, we tested whether such information would be sufficient to trigger task set activation all by itself. Hence, our dependent measure was not only the speed of task processing, but also the choice of task.

In the first experiment (Experiment 6), we presented masked and non-masked task cues on a trial-to-trial basis. Target stimuli were the numbers 1 to 9, excluding the 5, and participants made manual binary-choice responses to indicate either the magnitude (smaller vs. larger than 5) or the parity of the target number (odd vs. even). The two tasks were signaled by the letters w and b, which in the test language (German) bear no relation to the names of the tasks. In some trials, these task cues were non-masked and appeared for 150 ms, and thus clearly visible. In these trials, participants should have no difficulty to consciously identify the cues and prepare the corresponding task. In other trials, however, cues were presented only briefly (30 ms) and sandwiched by masks. In these trials, participants should be unable to become aware of the cues (an assumption that we tested in a separate recognition test), in which case they were instructed to choose freely which task to carry out on the target stimuli, with the restriction that each task should be chosen approximately equally often. In this respect, these trials resemble voluntary task switching (e.g. Arrington & Logan, 2004b, 2005; Forstmann, Brass, Koch, & von Cramon, 2006; Mayr & Bell, 2006).

In voluntary task switching, the task to perform is internally generated by the participant, as no cue or fixed task sequence predetermines the task in any trial. Despite this voluntary decision for a task repetition or switch, robust switch costs emerge in this paradigm. Also, other basic phenomena in task switching can be observed and seem to be independent of the experimental design (Yeung, 2010). Some studies, in contrast, suggest that cued task sets may be activated in a different way than internally selected ones (Forstmann, et al., 2006; Gollan & Ferreira, 2009). By additionally presenting a masked task cue during the voluntary task selection, we explore whether task choice processes are susceptible to

unconscious influences. Without conscious knowledge of the masked task cue, the subsequent choice of a task is internally determined, at least at the level of phenomenal experience. So our study does contribute to the debate about differences between externally and internally generated task sets. Finally, in contrast to earlier studies using a masked prime and a visible task cue, we were able to explore if cognitive control processes can be triggered by unconscious stimuli alone without additional visible stimuli.

When participants are allowed to “freely” chose the task they want after a masked cue, there is obviously no experimental control any more on whether the next trial would be a task switch or task repetition. To gain such control we devised a two-trial design structure, and focused on performance on the second trial of such trail pairs. Each pair of trials consisted of a first trial in which the cue was always clearly visible, and a second trial in which the visibility of the cue was varied (half of the cues were non-masked, the other half masked). After the second trial, the participants were asked to indicate which task they had actually performed in this second trial. This two-trial procedure allows us to clearly determine if the second trial is a repetition or a switch trial because task identity in the first trial is always instructed by clearly visible cues.

Our main question was whether masked—and presumably invisible—cues would be able to directly prime task set activation. If so, participants should exhibit a significant tendency to carry out the task indicated by the cues.

8.1 Method (Experiment 6)

8.1.1 Participants

Twenty-four students (eight males) of the University of Würzburg with an average age of 22 years participated in the experiment in fulfillment of course requirements or payment (6 Euro). All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

8.1.2 Apparatus and Stimuli

The experiment took place in a dimly lit room. An IBM compatible computer with a 17 inch VGA-Display and the software package E-Prime™ were used for stimulus presentation and response sampling. Stimulus presentation was synchronized with the vertical retraces of a 100-Hz monitor. Responses were executed with the index fingers of both hands and collected with external response keys. All stimuli were presented in white on a black background. Cues were either the letter w or b, and targets were the numbers 1 to 9, excluding the 5. In trials with masked primes, the pre- and postmask consisted of a random string of 5 Greek letters (chosen from Ω, Π, Σ, Δ, Φ, Γ, Θ, Λ, Ψ, or Ξ).

8.1.3 Procedure and Design

Throughout the whole experiment, trials were presented in pairs (see Figure 8). In the first trial of each pair (Trial I), a non-masked, clearly visible task cue was presented for 150 ms. After a blank screen of 100 ms, the target appeared and lasted until a response was given. Next to an inter-trial-interval of 1000 ms, the second trial of the pair (Trial II) started with a 70 ms premask. Then the task cue was presented, either for 150 ms without a postmask (non-masked) or for 30 ms

and followed by a 120 ms postmask (masked). After a blank screen of 100 ms, the target appeared until a response was given.

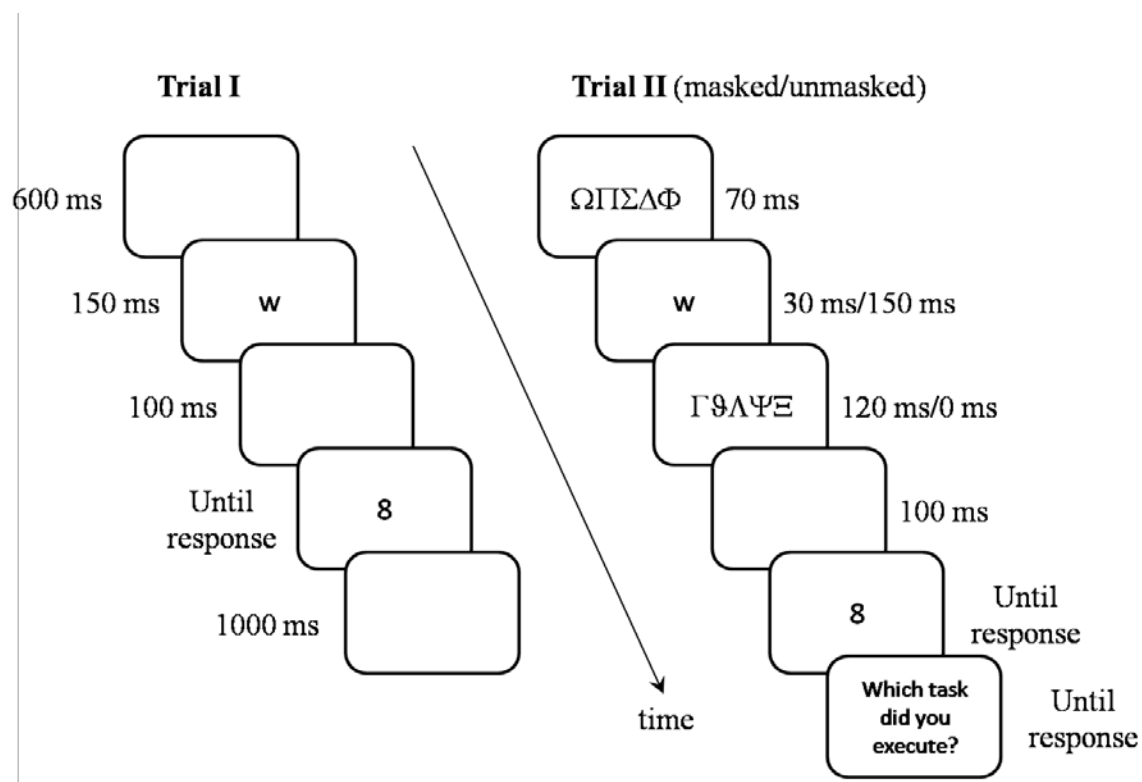


Figure 8. Sequence of events in the trial pairs. In the first trial of each trial pair (Trial I), the cue is always unmasked. In the second trial of each trial pair (Trial II), the cue is presented either unmasked with a duration of 150 ms or masked with a duration of 30 ms.

Participants were instructed to respond as fast and as accurate as possible. The mapping for both tasks (smaller/larger – left/right response; odd/even – left/right response) and the task cue letter to task assignment (w/b – magnitude/parity task) was counterbalanced across participants. At the end of Trial II participants were presented with the question “Welche Aufgabe hast Du als 2. Aufgabe ausgeführt?” (German for “Which task did you execute as the second task?”) and had to indicate their task choice by pressing the 1- or 3-key on the number keyboard. This response was not speeded. After an inter-trial-interval of

600 ms, the experiment continued with the next trial pair. The data analysis was restricted to the data from Trial-II trials.

Each possible combination of task cue and target (2 letters x 8 numbers) was used for both types of trials, which leads to 16 x 16 possible combinations of trial pairs. Considering the factor cue visibility in Trial II, this amounts to 512 trial pairs overall. After a practice block of 32 trials which featured only supraliminal cues, these 512 trial pairs were presented in pseudo-random order in blocks of 64 trial pairs with self-paced breaks between blocks. An experimental session lasted approximately 60 min.

8.1.4 Assessment of Cue Visibility

A visibility test with 96 trials was presented directly after the main experiment. Participants were fully informed about the structure of a trial and the presence of masked task cues. They had to perform a forced-choice discrimination task. For this task, we applied only masked cue trials for which the sequence of stimuli was exactly the same as in the main experiment. Participants were asked to identify the cue and had to press the according key (w or b) on the keyboard. Participants were instructed to take their time and to try to be as accurate as possible. In order to avoid that unconscious priming effects influence the free response choice (Kiesel, Wagener, et al., 2006; Schlaghecken & Eimer, 2004), there was an interval of 800 ms after target offset in which no response was possible (see Vorberg et al., 2003).

While detection performances may vary throughout an experiment, we chose not to test cue visibility after each trial, but at the end of the experiment, as is the state of the art procedure in this field of research. One advantage of this approach is that participants are not informed about the presence of masked cues

until the end of the main experiment. This also leads to a conservative estimate of subjective cue visibility, as during the visibility test, participants are aware of the presence of masked cues and focus their attention on the detection of these, which is not the case in the main experiment. This procedure is additionally conservative because participants have maximum training with the masked stimuli and visibility tests tend to be higher for more practiced stimuli (cf. Pohl et al., 2010). This, in our view, outweighs other factors like fatigue that may lead to an underestimation of d' values.

8.2 Results (Experiment 6)

Only the data from Trial-II trials were analyzed (in Trial I, mean RTs were 1147 ms with a mean error rate of 10.0%). Accordingly, the factor task repetition/switch refers to the relationship between the tasks performed in Trial II and in the preceding Trial I. We analyzed data from trials with masked cues and trials with non-masked cues separately. In both cases, we first analyzed whether the cues had an effect on the task choice, that is, how often participants chose the cued task and the non-cued task. To assess task performance in trials with non-masked cues, we then analyzed RTs and errors as a function of task repetition/switch. In trials with masked cues, we analyzed whether the task choice (cued task vs. non-cued task was performed, as indicated by the participants at the end of Trial II) and task repetition/switch affected RTs and error rates. For the RT analysis, error trials and trials with RTs deviating more than 2.5 standard deviations from the mean RT of each participant and each condition were excluded. In trials with masked cues, error trials were defined as trials in which the participant made an error with respect to the task he/she reported to have performed, not with respect to the task that was cued.

8.2.1 Non-masked Cues

Task choice. Participants performed the cued task in 93.0% of the trials (see Figure 9). That is, in 7.0% of the trials participants chose the wrong task or made an error when reporting the performed task at the end of the trial.

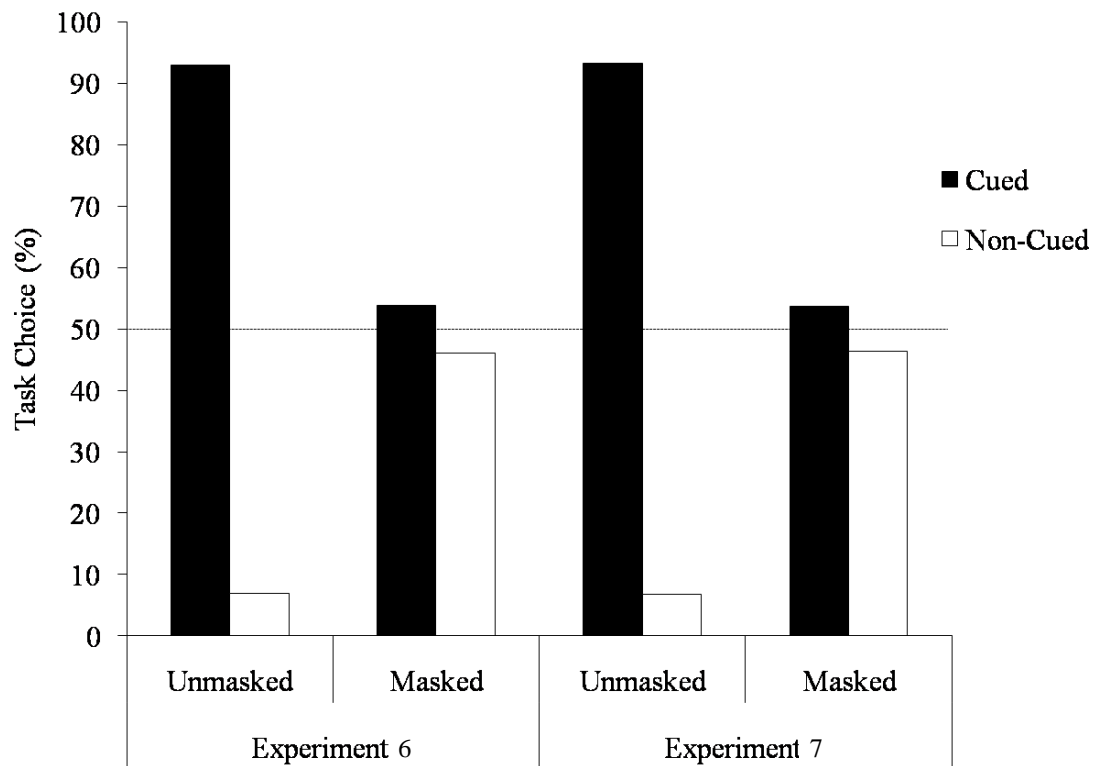


Figure 9. Proportions of participants' choices of cued and non-cued tasks for unmasked and masked cues in both experiments.

RT and error rates. Participants responded faster (843 ms vs. 1055 ms) in task repetition than in task switch trials, $t(23) = 5.27$, $p < .001$, and they made marginally fewer errors (6.9% vs. 8.4%) in task repetition than in task switch trials, $t(23) = 1.96$, $p = .062$.

8.2.2 Masked Cues

Task choice. Participants reported to have performed the task that was indicated by the cue in 53.9% of all trials (see Figure 9). This differs significantly from chance level of 50%, $t(23) = 2.32$, $p = .029$.

We further analyzed if participants were biased to repeat or to switch the task, as in voluntary task switching, a repetition bias is typically found. Indeed, we observed a tendency to repeat the task. Participants repeated the task from Trial 1 in 62.3 % of all trials, which differs significantly from chance level, $t(23) = 4.29$, $p < .001$. Task choice did not influence this repetition bias, $t(23) = 1.54$, $p = .137$, which was found both when the task was performed according to the task cue (61.9% repetitions) and when it was not performed according to the task cue (63.1% repetitions).

RT and error rate. RT and error rate data were submitted to a 2 x 2 repeated measures ANOVA with the within-subject factors task choice (cued task was performed vs. non-cued task was performed) and task repetition/switch (means are shown in Table 1). RT analysis revealed a main effect of task repetition/switch, $F(1, 23) = 20.56$, $p < .001$. Participants responded faster in task repetition trials (1182 ms) than in task switch trials (1445 ms). The main effect of task choice was also significant, $F(1, 23) = 7.45$, $p = .012$. Participants responded faster (1283 ms) when they executed the cued task than when they executed the non-cued task (1344 ms). Both factors did not interact, $F(1, 23) < 1$.

Analysis of error rates revealed a main effect of task repetition/switch, $F(1, 23) = 7.94$, $p = .01$. Participants made fewer errors (6.9%) in task repetition trials than in task switch trials (11.6%). The main effect of task choice was not significant, $F(1, 23) = 2.20$, $p = .152$. The interaction between task choice and task

repetition/switch was significant, $F(1, 23) = 5.49, p = .028$. Participants made more errors (13.1% vs. 10.1%) when they performed the cued task than when they performed the non-cued task in a task switch trial, $t(23) = 2.16, p = .042$. In trials with task repetitions, error rates did not depend on task choice, $t(23) = .60, p = .552$.

Table 1

Mean performance scores for RT (ms) and error rate (%) in Experiment 6 and 7.

	Experiment 6			Experiment 7		
	Cue Visibility			Cue visibility		
	Unmasked Cue	Masked Cue		Unmasked Cue	Masked Cue	
		Cued task	Non-Cued task		Cued task	Non-Cued task
RT						
Repetition	843	1156	1207	1116	1192	1201
Switch	1055	1411	1480	1359	1584	1579
Error rate						
Repetition	6.9	6.7	7.2	3.5	1.8	2.8
Switch	8.4	13.1	10.1	6.7	7.2	11.1

8.2.3 Cue Visibility

Cue visibility was assessed by computing the signal detection measure d' , treating the cue w as signal and the cue b as noise. Participants' discrimination performance for the fully masked cues was $d' = 0.29$, with a mean hit rate of 53.3% and a mean false alarm rate of 43.6%. This value tended to deviate from zero $t(23) = 1.98, p = .06$.

To further rule out that partially visible cues may account for the observed effects, we assessed the relationship between each participant's individual d' score and the effect of masked cues on RT. We adopted a procedure advocated by Greenwald and colleagues (1995; see also Draine & Greenwald, 1998; Greenwald, et al., 1996) and regressed the RT difference of trials with cue-consistent task choices and trials with cue-inconsistent task choices onto individual d' scores. We found that the intercept of the regression model was significantly positive at 50 ms ($p = .046$). This indicates that the significant effect of task choice on RT is observable even with a d' value of zero and thus presumably at zero visibility. Additionally, this analysis showed that d' scores and the effect of task choice on RT are not significantly correlated ($r = .227$, $p = .287$), which further implies that the observed effects are independent of individual cue visibility and are not due to conscious perception of some of the cues.

8.3 Discussion (Experiment 6)

In trials with non-masked cues, the results replicate the typical finding of task switching studies by showing better performance for task repetitions than task switches. Furthermore, participants indicated to have performed the cued task in most of the trials, confirming that participants followed the instructions and suggesting that the cues were clearly visible.

More importantly, there are two findings that reveal an impact of masked task cues on task set activation: Participants chose the cued task more often than the non-cued task and they were faster performing the cued than the non-cued task. Both findings seem to indicate that the masked cues activated task sets. The influence on task choice reflects an activation of the cued task that induces a bias to actually perform this task. Analogue to the findings that the free choice of motor

responses is influenced by masked primes, possibly through motor preactivation (Kiesel, Wagener, et al., 2006; Schlaghecken & Eimer, 2004), the free choice which task set to apply seems to be influenced by the masked cues. Furthermore, the faster responses in the cued task seem to suggest that the currently required S-R-mapping (which is an instance of the task set) was more active for the cued task. This enabled participants to apply the S-R-rules faster and thus to respond more quickly to the target if they performed the cued task.

Regarding the task choice, it would have been theoretically possible for participants to randomly respond before they actually decided which task to perform and then to “reconstruct” which task fits their response and accordingly answer the question which task they performed. Such a strategy would, however, lead to a certain error pattern: With incongruent targets, a “correct” task to whatever response can be reconstructed, and thus any errors at all would only occur when the task is wrongly reconstructed. With congruent targets, in contrast, half of the possible responses are incorrect for both tasks, which would thus lead to noticeably high error rates. An analysis of error rates with the additional factor of target congruency shows that error rates for congruent and incongruent targets in masked trials do not differ significantly, $p = .244$, while there were actually (which is a typical finding in task switching) less errors with congruent targets (6.9 %) than with incongruent targets (9.2%). Thus, we consider a strategy of post hoc task reconstruction highly unlikely.

Even though these results are consistent with the idea that unconscious stimuli can trigger task set activation, there is an important objection one might raise. In a typical task switching experiment, participants may respond correctly without performing different tasks at all, and thus without actually switching task

sets. Instead, it is possible to map the responses directly to a combination of both the cue and the target. This strategy was proposed by Logan and Bundesen (2003, 2004) and is referred to as a compound stimulus strategy. In short, the compound stimulus strategy states that “subjects encode the cue, encode the target, and respond to the compound” (Logan & Bundesen, 2004, p. 839). Imagine that, for example, for one given participant the task cues *w* and *b* signal the parity and the magnitude task, respectively. Further assume that a left key response is required for odd and smaller than 5 judgments, while a right key response signals even and larger than 5 judgments. When responding, the participant may not apply any knowledge regarding the magnitude task and the parity task but respond to the combination of cue and number instead. Thus, he or she might press the left key whenever the cue-target combination is *w*1, *w*3, *w*7, *w*9 (for odd numbers in the parity task), or *b*1, *b*2, *b*3, and *b*4 (for small numbers in the magnitude task), and the right key for the other combinations.

The compound stimulus strategy, as Logan and Bundesen noted (see also Arrington & Logan, 2004a), can be interpreted in two ways. The first approach is to use cues and targets and directly associate them with a response in episodic memory without interpreting them. In the given example, the cue *w* and the target 9 always lead to the left key response. Once this cue target combination was presented and the participant has responded, the cue target compound consisting of both stimuli is stored in episodic memory and associated with the left side response. When the cue target compound is perceived again, the participant retrieves the memorized association between cue target compound and the correct key press to execute the response. A second possibility is that the participant interprets the cue and the target, and uses the combination of both (the

compound retrieval cue) to retrieve the necessary information from semantic memory (e.g. the cue *b* and the target 9 retrieve “odd”, and the corresponding response is executed). This is especially plausible with familiar stimuli like numbers, with which categories like *odd* or *even* are already available in semantic memory (Arrington & Logan, 2004a). This compound cue retrieval strategy uses only one task set consisting of the mapping of categories to responses like odd-left, even-right, smaller-left, and larger-right. In each trial processing involves to identify the cue, identify the target, and respond according to what the joint retrieval cue pulled from memory. In either case, the results of Experiment 6 can be interpreted as a result of stimulus compound strategies, in which the masked cue in combination with the target activates the response without activating task sets.

To rule out that participants apply the stimulus compound strategy, we devised another experiment in which cue target compound strategies were not viable by using transition cues (see Forstmann, Brass, & Koch, 2007; Forstmann, Brass, Koch, & von Cramon, 2005; Rushworth, Hadland, Paus, & Sipila, 2002; Schneider & Logan, 2007) instead of task cues.

In standard task switching experiments, each task cue is associated with a specific task and thus tells the participant directly which task to apply. This leads to the possibility of the aforementioned stimulus compound strategy which allows correct responding in task switching experiments without actually switching between the tasks. One method to avoid this problem is to use transition cues instead of task cues. Transition cues are not associated with any particular task but instruct the participant to either repeat the just-performed task or to switch the task. We used the cue *b* to signal a repetition of the preceding task, and the cue *w*

to signal a switch to the other task. Now, a combination of the cue and the target does not give sufficient information to determine the required response, as the same cue target combination can result in different responses, depending on the task performed in the preceding trial. Whereas a cue in the previous experiment was always linked to a certain task, and in combination with the target to a certain response, transition cues result in either task, requiring different responses to the same cue target combination, thus rendering stimulus compound strategies useless.

8.4 Method (Experiment 7)

8.4.1 Participants

Fifteen students (13 females) of the University of Würzburg with an average age of 22 years participated in this experiment in fulfillment of course requirements or payment (6 Euro). All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

8.4.2 Apparatus, Stimuli, Procedure, and Design

Apparatus, stimuli, procedure, and design were the same as in Experiment 6. Instructions differed only regarding the use of transition cues. Participants were instructed to perform the task that was directly indicated in Trial I by the cue “Größe” (German for “magnitude”) or “Parität” (German for “parity”), and to repeat this task if the cue *b* was presented in Trial II, and to switch to the task that was not performed in Trial I if the cue *w* was presented in Trial II.

8.5 Results (Experiment 7)

As in Experiment 6, only data from Trial-II trials were analyzed. For the RT analysis, trials with RTs deviating more than 2.5 standard deviations from the mean RT of each participant and each condition were excluded, as were trials containing errors. In trials with masked cues, error trials were defined as trials in which the participant made an error with respect to the task he reported to have performed, not the task which was cued.

8.5.1 Non-masked Cues

Task choice. Participants performed the cued task in 93.2% of the trials (see Figure 9). That is, in 6.8% of the trials participants chose the wrong task or made an error when reporting at the end of the trial which task was performed.

RT and error rates. Participants responded faster with task repetitions (1116 ms) than task switches (1359 ms), $t(14) = 6.47$, $p < .001$, and made fewer errors with task repetitions (3.5%) than task switches (6.7%), $t(14) = 5.23$, $p < .001$.

8.5.2 Masked Cues

Task choice. Participants chose the task that was indicated by the cue in 53.7% of these trials (see Figure 2). This differs significantly from chance level, $t(14) = 2.40$, $p = .031$.

We observed a tendency to repeat the task. Participants repeated the task from Trial I in 65.1 % of all trials, which differs significantly from chance level, $t(23) = 3.30$, $p = .005$. Task choice did not influence this repetition bias, $t(23) = 0.634$, $p = .536$, which was found both when the task was performed according to the

task cue (65.3% repetitions) and when it was not performed according to the task cue (65.0% repetitions).

RT and error rates. RTs and error data were submitted to a 2 x 2 repeated measures ANOVA with the factors task choice (cued task was performed vs. non-cued task was performed) and task repetition/switch (means are shown in Table 1). There was a main effect of task repetition/switch, $F(1, 14) = 13.28, p = .003$, with mean RTs of 1196 ms for task repetitions and mean RTs of 1581 ms for task switches. Task choice did not influence RT, $F(1, 14) < 1$, with mean RTs of 1390 ms for non-cued and 1388 ms for cued task performance. The factors task choice and task repetition/switch did not interact, $F(1, 14) < 1$.

For error rates, there was a main effect of task repetition/switch, $F(1, 14) = 12.41, p = .003$, with mean error rates of 2.3% for task repetitions and 9.1% for task switches. Further, there was a main effect of task choice, $F(1, 14) = 5.44, p = .035$. Participants made fewer errors when they performed the cued task (4.5%) than when they performed the non-cued task (6.9%). The interaction of task repetition/switch and task choice was marginally significant, $F(1, 14) = 4.25, p = .058$. In switch trials, participants made fewer errors when they performed the cued task (7.2%) compared to the non-cued task (11.1%), $t(14) = 2.64, p = .019$, whereas in repetition trials, task choice had no impact on error rates, $t(14) = 0.96, p = .355$.

8.5.3 Cue Visibility

Participants' discrimination performance for the fully masked cues was $d' = -.05$, and did not deviate from zero $t(14) = -.636, p = .54$. Thus, participants were not able to discriminate the primes.

8.6 Discussion (Experiment 7)

In contrast to Experiment 6, stimulus compound strategies were not viable in Experiment 7, and yet, participants still chose the cued task more often than the non-cued task. This suggests that the transition cues, though not consciously perceived, activated the corresponding task set, which in turn induced the tendency to perform that task. However, task performance was only slightly influenced by the masked cues. Mean response times did not differ for cued and non-cued tasks and error rates differed only in task switch but not in task repetition trials. Hence, participants chose the cued task more often than the non-cued task but did not execute it any faster, as was the case in Experiment 6. This suggests that the impact on RTs observed in Experiment 6 was a consequence of the presence of cue-target compounds.

8.7 General Discussion (Experiments 6 and 7)

The aim of the present study was to investigate whether subliminally presented stimuli can activate task sets under experimental conditions that rule out possible artifacts due to prime-cue interactions. Experiment 6 provided preliminary evidence that even masked, and presumably subjectively invisible task cues can trigger task set activation. However, the design of this experiment could have led participants to make use of the cue-stimulus compound strategies considered by Logan and Bundesen (2004). These strategies were prevented by the design of Experiment 7, where cues no longer signaled a particular task but, instead, informed participants to stay on the same task or to switch. Accordingly, there was no contingency of tasks and cues, which rules out any contribution from cue-task or stimulus-cue-task associations or learning. Nevertheless, masked transition

cues affected the choice of tasks, even though the speed of task performance was unaffected.

Task set activation in response to a randomly varying cue is widely considered a cognitive control process (e.g., Altmann, 2004; Hoffmann, Kiesel, & Sebold, 2003; Koch, 2001; Meiran, 1996; Rogers & Monsell, 1995) that requires conscious awareness (Dehaene & Naccache, 2001; Jack & Shallice, 2001; Smith & Jonides, 1999; see Hommel, 2007, for an overview). Our observation that task choices are impacted by stimuli that participants are not aware of is inconsistent with this assumption and suggests that processing of masked cues is not fundamentally different from processing of non-masked cues, and that conscious awareness has no functional role in task set activation. This conclusion is consistent with previous claims (Mattler, 2003, 2006), but, as we have explained, is based on what we consider more solid evidence that cannot be accounted for in terms of perceptual priming or prime-cue interactions. Our results fit and add nicely to the fMRI study of Lau and Passingham (2007) that likewise suggested that task sets can be activated by unconscious stimuli. Moreover, we could also show that unconscious stimulus information can trigger task set activation all by itself without additional presenting visible stimuli. Whereas possible differences regarding task set activation (and other aspects) between externally cued tasks and internally selected tasks are still under debate, this result shows that task set activation is susceptible to unconscious influences regardless of the specific experimental design.

This conclusion fits with observations from studies on the implicit learning of task-switching sequences (Gotler, Meiran, & Tzelgov, 2003; Koch, 2001). In the study of Koch (2001), participants were cued to switch between three tasks.

However, instead of the typical random sequence of tasks, there was a fixed task sequence that repeated every 9 trials. Participants were not informed about this fixed sequence and were unable to report any knowledge of the task sequence after the experiment. Yet, when the fixed sequence was replaced by another task sequence, overall RT increased. This suggests that the task sets that accorded to the fixed sequence were unconsciously activated, thus reducing RT with the fixed sequence and prolonging RT when the sequence changed. A problem with this design was that the fixed task sequence went along with a fixed cue sequence. Gotler and colleagues (2003) used a fixed task sequence, but applied two cues per task to disentangle task sequence and cue sequence. Results were comparable to those by Koch, with longer RTs in the fixed sequence blocks than in random blocks. Thus, these studies demonstrated some kind of “automatic ‘priming’ of task-sets that is not mediated by intentional processes” (Koch, 2001, p. 1478).

The fact that masked task cues affect both task choices and the speed of task performance (Experiment 6), whereas masked task-transition cues affect task choices only (Experiment 7) provides a theoretically important hint to the underlying mechanisms. Several authors have suggested two-stage models of task switching that, roughly speaking, distinguish between processes devoted to the selection of a task set and processes responsible for the implementation of this task set (e.g., Koch & Allport, 2006; Mayr & Kliegl, 2000; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001). For example, Rubinstein and colleagues (2001) distinguish between *goal shifting* and *rule activation*. The goal shifting stage’s function is to identify and keep track of the currently relevant task, whereas the rule-activation stage is responsible for the implementation of the relevant

stimulus-response mappings. In the explicit cuing paradigm, the task cue would provide the information which task to perform next, which first leads to the selection of the appropriate goal (task) and then to the activation of the corresponding mappings. From this perspective, our findings might be taken to imply that masked task cues affect both stages whereas masked transition cues affect goal selection only. Yet, as task switching theories differs immensely regarding the underlying processes when switching between different tasks, these considerations should be seen as speculative at the moment.

The reason for the different findings regarding task and transition cues is likely to be related to the fact that task cues are contingent on particular tasks, whereas transition cues are not. This means that a given task cue is likely to become associated with the representation of the task and the task-specific mappings it signals, just like a conditioned stimulus becomes associated with the unconditioned stimulus it precedes in time. In contrast, transition cues precede each task equally often and should thus be associated with all task representations alike. If we now assume that the choice of a task is affected by the information a task or transition cue provides, whereas the speed to execute a stimulus-response rule is affected by the degree to which a set of task-specific rules is primed by existing cue-mapping associations, it is clear that transition cues can only target task choices while task cues can affect both task choice and rule execution. This scenario also seems to fit with the idea of Forstmann and colleagues (2007) that “direct task cues may lead to automatic activation of the associated task set, whereas such direct, stimulus-based automatic task-set activation is not possible when using transition cues” (p. 398).

To conclude, we found evidence that the activation of task sets can be affected by stimuli that people are not aware of, even under conditions ruling out perceptual priming and prime-cue interactions. This adds to the increasing evidence that cognitive control processes are systematically affected by unconscious information. However, what exact process is impacted depends on the type of stimulus. Unconscious stimuli that are uniquely associated with particular task sets seem to activate all the stimulus-response mappings the set comprises of, thereby speeding up performance based on these mappings. In contrast, unconscious stimuli that point to a particular task, but that are not contingent on a specific task or task elements, can bias or even induce the decision which task to perform, but do not speed up the subsequent performance of the task. This dissociation is consistent with dual-process models of task switching in general and with models distinguishing between goal selection and task set implementation in particular.

9. General Discussion

9.1 Top-down control modulates unconscious processing

The first goal of this thesis was to investigate how the processing of unconsciously presented stimuli is influenced by top-down settings. The results of studies that compared the effects of masked primes on experts and on novices already suggested that unconscious processing is not automatic in the sense that it works independent of top-down control, but that expertise can be a crucial factor for the effectiveness of masked primes (Heinemann et al., 2010; Kiesel et al., 2009). When participants had to decide whether a checking or non-checking chess configuration was presented on a 3x3 chess board, only the responses of chess experts were influenced by according masked chess board primes. For example, when the prime displayed a checking configuration, chess experts responded faster to the target when it also displayed a checking configuration compared to when it displayed a non-checking configuration. Strikingly, this impact of the masked primes was not present with chess novices. This finding implies that processing of complex chess-related stimuli is enhanced in chess experts compared to chess so that chess experts are able to elaborately process even unconsciously presented task-specific stimuli. However, due to the quasi-experimental nature of this study that relies on the comparison of pre-existing groups, it remains unclear whether other differences between the expert and novice groups (e.g., differences in intelligence, familiarity with computers, socioeconomic status) contaminated these results. We therefore devised an experimental design that manipulated the degree of expertise experimentally (see Experiment 1). All participants were from the same population, were presented with the same stimuli, and also had to respond in the same way to the stimuli. Yet,

while one group of participants were instructed to do a lexical decision task and thus could rely on their word reading expertise, the other group of participants was *de-expertised* by an instruction that explained the task in a way that did not address any domain of expertise. Any differential effects of masked primes between the two groups could thus unambiguously be linked to the experimentally created differences in expertise. We found that only participants that could rely on their reading expertise when performing the task were influenced by the response congruency of the masked primes. When participants had to process the stimuli in a novel way, masked primes had no effect on responding. This finding was therefore a demonstration that the exact same stimuli can both be effective and completely ineffective influencing our behavior when presented unconsciously, depending only on top-down influences.

In Experiments 2 and 3, we likewise investigated how currently active intentions determine the impact of masked stimuli. In a spatial cueing paradigm, we presented both visible and masked arrow cues and varied the overall validity of the cues. In Experiment 2, the cues were not predictive of the target location, but only indicated the correct target location in 50% of all trials. Participants thus had no incentive to actually use the cues to orient attention, as this offered no advantage for performance. In contrast, the cues in Experiment 3 predicted the target location correctly in 80% of all trials. Orienting of attention according to the cues was thus advantageous and presumably lead to the intention to use the cues. If the effect of the cues was truly automatic, they should impact on attention regardless of the participants' intention to use them (Shiffrin & Schneider, 1977). However, the results showed that the overall cue validity was crucial for the cues' effect. When the masked cues were not predictive of the target location, RTs did

not depend on cue validity, indicating that the masked cues were not able to impact on attention. When the cues overall validity was 80%, however, participants responded faster after valid than after invalid cues, crucially also when the cues were masked. The intention of the participant therefore was a central determinant of the cues' effectiveness.

This result is in line with findings that the impact of masked cues in semantic priming is modulated by currently active task sets. The attentional sensitization model (Kiefer, 2012) assumes that unconscious processing is only elicited when the cognitive system is configured accordingly. This model assumes a mechanism of attentional amplification of particular processing pathways that are contingent on the active task set. This is typically demonstrated with an induction task paradigm: Participants first execute a task that is meant to induce a particular task set, for example a semantic task vs. a phonological task. The occurrence of semantic priming in a subsequent priming task was found to depend on the task set that was induced before (Kiefer & Martens, 2010). The results at hand show that not only specifically induced task sets, but also the general intention to use particular stimuli determines the impact of masked stimuli. Applying the attentional sensitization model to these results would mean that the intention to pay regard to the arrow cues sensitizes the system to process arrow stimuli. This sensitization allows the masked arrow cues to exert an effect, while they remain ineffective when no such intention and thus no sensitization is present.

Overall, the results of Experiments 1-3 show that the effects of masked stimuli are not strictly automatic, but are instead crucially modulated by top-down influences like expertise or current intentions.

9.2 Unconscious stimuli impact on cognitive control

The second goal of this thesis was to investigate whether unconsciously presented stimuli can not only impact on perceptual and motor processes, but are even able to impact on cognitive control processes.

While Experiments 2 and 3 also investigated the influence of top-down control on unconscious processing, the results additionally indicate the bidirectional interplay of top-down control and unconscious processing by showing that orienting of attention can be induced unconsciously. After valid cues, responses were faster than after invalid cues, regardless of cue visibility. This finding, however, does not unambiguously demonstrate endogenous orienting of attention by masked cues, as it might be restricted to the specific type of cues that were used, namely arrows. Arrows, among other stimuli like pointing gestures and gaze cues, have been found to be able to impact on attention automatically (Hommel et al., 2001, Pratt et al., 2010). This is presumably due to the overlearned spatial effect of arrows we encounter in everyday life. Thus, to investigate whether shifts of attention can be induced unconsciously without the restriction to specific cue stimuli, we implemented spatial cues that had no pre-experimental spatial meaning in Experiments 4 and 5. As these spatial cues were presented not at the potential target location, but centrally, and additionally have to be interpreted regarding their spatial meaning according to the experimental instructions, shifts of attention induced by these cues would be considered endogenous and thus under cognitive control. An effect of masked cues would therefore cast doubt on the inherently assumed intentional and deliberate nature of such shifts of attention. Strikingly, we found in both experiments that even masked

cues were able to impact on attention. Participants oriented their attention according to the cues' meaning regardless of the visibility of the cue.

This result conflicts with previous findings by McCormick (1997), who found that while masked cues were able to draw attention to their position, participants were not able to willingly orient their attention according to the masked cue. One reason for these contradicting results might be the high vulnerability of unconsciously induced endogenous shifts of attention. This vulnerability was indicated by the data of Experiments 4 and 5, which showed that the effects of masked spatial cues are highly susceptible to potentially interfering other attentional processes (like previously cued shifts of attention). Effects in McCormick's study thus might have been suppressed by the experimental design that called for several shifts of attention in each trial. This finding also underlines that while unconsciously presented cues are in principal able to orient attention, their effects are still different from those elicited by visible cues. Here, both the robustness of the effect, and also its size differed considerably between consciously and unconsciously presented cues. Comparable results in this respect were found in Experiments 6 and 7.

In Experiments 6 and 7, the unconscious activation of task sets was investigated. Whereas earlier studies on this subject used masked primes that preceded visible task cues (Mattler, 2003, 2006; Lau & Passingham, 2007), a new methodological approach was used in these two experiments by directly varying the visibility of the cue. This experimental design allowed investigating whether task sets can be activated purely by unconsciously presented stimuli without the involvement of a visible cue, while also assuring that the effect of the masked stimulus is indeed due to an impact on central cognitive control processes (and

not located at early perceptual stages). The results showed that different aspects of task sets were influenced by masked task cues in Experiment 6. Both the task choice, which reflects an aspect of goal shifting, and RT, which reflects an aspect of rules activation, were influenced by the masked task cue. Participants chose the unconsciously cued task more often than the non-cued task, and they responded faster when they chose the cued task compared to the non-cued task. Experiment 7 featured transition cues that signaled either a task repetition or a task switch, so that the relation between a particular cue and which task it signaled depended on the previous task. Masked transition cues were still able to impact on task choice, but had no effect on RT. This indicated that masked transition cues still impacted on task set activation, but that they were only able to influence the goal shifting stage, but were not able to activate corresponding stimulus-response mappings.

Similar to the results of Experiments 4 and 5, these findings suggest that cognitive control processes that were traditionally conceptualized as being initiated deliberately to consciously control our behavior can in fact be triggered unconsciously. Taken together with other studies that reported analog results for other cognitive control processes (Hughes et al., 2009; van Gaal et al., 2008, 2009), these findings suggest that the concept of cognitive control and its inherently conscious nature as well as the limits of unconscious processing have to be reconsidered.

9.3 New limits of unconscious processing

When one considers the development of what was thought of as the limit of unconscious processing, it becomes clear that this limit is pushed continuously further to more and more processes. While at first, the phenomenon of subliminal priming was met with principal skepticism and methodological doubts (Cheesman

& Merikle, 1984; Holender, 1986). Later, it became an established and widely accepted finding that motor processes can be influenced by masked stimuli (Greenwald et al., 1996; Klotz & Neumann, 1999). However, just 12 years ago, an impact of an unconscious stimulus on top-down control was generally considered an “impossible situation” (Dehaene & Naccache, 2001, p. 21). In the meantime, this notion was by and large shown to be not true by a plethora of studies (Hughes et al., 2009; Mattler, 2006; Lau & Passingham, 2007; van Gaal et al., 2008, 2009) that are further corroborated by the findings presented in this thesis. Consequently, one has to ask whether finally a limit to the potency of unconscious processing can be found, or whether it will be determined that there is no principal difference between the processing of conscious and unconscious stimuli.

When looking for findings that showed a prerequisite of conscious awareness for particular processes to be engaged, it is conspicuous that the majority of studies concerning the adaptation to conflict in conjunction with unconscious stimuli found that conscious conflict awareness was crucial for conflict adaptation to take place (Kunde, 2003; Heinemann et al., 2009; Ansorge et al., 2011; but see van Gaal et al., 2010). One potentially important difference between the experimental paradigms used to study conflict adaptation and the experimental paradigms to study other processes like inhibition or task set activation is that with the latter, there is always an explicit cue that asks for a particular control process. In the Go/NoGo or stop signal paradigms, there is a stimulus that tells the participant to inhibit responding. In the task switching paradigm, there is a task cue that indicates which task set to activate. With conflict adaptation, however, there is no explicit cue that asks for conflict adaptation, but the need for it has to be determined through the accumulation and combination of

information. Even in its simplest form, the adaptation to recent conflict (Gratton et al., 1992), one has to consider the information of the irrelevant stimulus (e.g., the prime), the information of the relevant stimulus, and how they relate to each other. This combined information has to be kept active at least until the next trial to be able to adapt stimulus processing accordingly.

Kunde, Reuss, and Kiesel (2012) argued that the main mechanism for the different findings lies in the distinction between explicit and implicit events that ask for cognitive control. When implicit events ask for cognitive control, this is dependent on the conscious representation of all information that is involved due to the more elaborate underlying mechanisms described above. In contrast, once the connection between an explicit stimulus and the corresponding cognitive control process has been established, which is possible because the explicit stimulus is presented visibly in some trials, the explicit stimulus can trigger cognitive control processes even when presented unconsciously. The critical variable is thus not the control process per se, but how the necessary control process is indicated. When it is indicated explicitly, that is, in the form of “If *X* is present, then always do *Y*”, a conscious representation of the stimulus is not necessary, even when *Y* is a cognitive control process. However, when information has to be derived from implicit events in the environment, conscious representations are crucial.

A seemingly secondary finding in Experiments 6 and 7 fits this assumption: When task set activation was signaled by explicit task cues, both task choice and task execution were influenced when the cues were masked. However, when transition cues were used, the influence of masked cues was significantly reduced. The task cue is explicit in the sense that it is always associated with the same

control process. The transition cue, however, is not always associated with the same control process, but the association depends on the previous task. Thus, previous task information has to be kept available and combined with the current cue information. Therefore, while a transition cue resembles an explicit cue in the sense that it is a distinct, single stimulus, it requires the maintenance and combination of information that is typical for implicit events that ask for cognitive control. It therefore fits nicely that its impact is reduced when presented unconsciously, but not completely absent.

To establish the limits of unconscious processing, it seems promising to further investigate why many cognitive control processes are susceptible to unconscious stimulation, while others like conflict adaptation are not. One possibility to determine whether the proposed influence of explicit vs. implicit events that ask for cognitive control is not without merit, or whether it is in fact the nature of the process (i.e., conflict adaptation per se requires consciousness) would be to find a way to explicitly indicate processes that are typically indicated implicitly (e.g., with some kind of explicit conflict adaptation cue), or to implicitly indicate control processes that have been found to be susceptible to explicit unconscious stimulation. Another line of research to investigate the upper limits of unconscious processing is to address potential prerequisites that might be necessary to enable an unconscious impact on conflict adaptation. It is feasible that the conditions in hitherto studies regarding conflict adaptation (e.g., timing of stimuli, frequency of conflict) were simply unfavorable for unconscious influences, so that a systematic approach is needed to help define the limits of unconscious processing.

9.4 Final summary and conclusion

The goal of this thesis was to investigate both to what extent unconscious processes are influenced by top-down settings and to what extent unconscious processes are in turn able to influence processes of top-down control. I found that the effectiveness of unconsciously presented stimuli depends profoundly on top-down settings. In Experiment 1, masked primes only exerted an effect on motor responses when the participants were instructed to judge the lexical status of stimuli. This task enabled the masked stimuli to be processed by addressing the participants' expertise in word reading. When the same stimuli had to be processed in a way not related to expertise, the masked primes were not able to impact on responses. Experiments 2 and 3 likewise demonstrated that specific task settings like the intention to use the information provided by cues determine the effect of those cues when they are masked. When a centrally presented arrow cue indicated the location of a subsequent target rather reliably so that the participant had an incentive to use the cues, these cues lead to shifts of attention even when they were masked. When usage of the cues offered no strategic advantage because they were not predictive of the target location, masked cues were not able to induce shifts of attention. Besides the influence of top-down settings, Experiment 3 also showed that orienting of attention as an instance of cognitive control can be influenced by masked stimuli. To extend on these findings, Experiments 4 and 5 featured centrally presented spatial cues that, unlike arrows, are not pre-experimentally associated with spatial attributes. The results confirmed that orienting of attention due to a centrally presented spatial cue, which is considered to be endogenously controlled, can be influenced by cues that the participants were not aware of. Finally, I investigated whether such an impact of

unconscious stimuli on cognitive control can also be demonstrated for task set activation, one of the central cognitive control processes. The results showed that task sets activation can be triggered by unconsciously presented task cues. Participants chose the unconsciously cued task more often than the non-cued task (Experiments 6 and 7), and when they did so, they responded faster than when they chose the non-cued task (Experiment 6).

While these findings unequivocally show that top-down control can be evoked by unconsciously presented stimuli, the results might be restricted to cases in which the masked stimuli are mixed with visible stimuli that explicitly call for cognitive control. Future research therefore has to investigate the critical variables that determine effects of unconsciously presented stimuli and thus define the limits of unconscious processing.

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