DEMONSTRATING PERCEPTION WITHOUT VISUAL AWARENESS: DOUBLE DISSOCIATIONS BETWEEN PRIMING AND MASKING

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[1] I was on parental leave from May 2018 until March 2020.

Publishing note

During my Ph.D. I worked on several projects as co-author. These projects are already published, but *not* part of my present thesis:

- Haberkamp, A., Biafora, M., Schmidt, T., & Weiß, K. (2018). We prefer what we fear: A response preference bias mimics attentional capture in spider fear. *Journal of Anxiety Disorders*, *53*, 30–38. https://doi.org/10.1016/j.janxdis.2017.10.008

- Haberkamp, A., Schmidt, F., Biafora, M., & Schmidt, T. (2019). Interpreting and responding to ambiguous natural images in spider phobia. *Journal of Behavior Therapy and Experimental Psychiatry*, *65*, 101495. https://doi.org/10.1016/j.jbtep.2019.101495

Additionally, two manuscripts with first authorship and two manuscripts as second co-author emerged under the supervision of Prof. Dr. Thomas Schmidt during my work in the department of Psychology at the University of Kaiserslautern:

- Biafora, M., & Schmidt, T. (2020). Induced dissociations: Opposite time courses of priming and masking induced by custom-made mask-contrast functions. *Attention, Perception, & Psychophysics*, *82*, 1333–1354. https://doi.org/10.3758/s13414-019-01822-4

- Biafora, M., & Schmidt, T. (2021). *Juggling too many balls at once: Qualitatively different effects when measuring priming and masking in single, dual, and triple tasks* [Manuscript submitted for publication]. Department of Psychology, University of Kaiserslautern.

- Schmidt, T., & Biafora, M. (2021). *A theory of visibility in the dissociation paradigm* [Manuscript submitted for publication]. Department of Psychology, University of Kaiserslautern.

- Schmidt, T., & Biafora, M. (in press). Explaining the gradient: Requirements for theories of visual awareness. Open peer commentary on the target article by

Merker, B., Williford, K., & Rudrauf, D. (2021). The Integrated Information Theory of consciousness: A case of mistaken identity. *Behavioral and Brain Sciences*, 1-72. https://doi.org/10.1017/S0140525X21000881

The papers with first authorship are part of my dissertation and have been adopted to meet the requirements of my present thesis. Most changes have been made in the introductions and discussions. Accordingly, the introductions, methods, results and discussions of the experiments mainly correspond to the respective manuscripts that were *submitted for publication* (Biafora & Schmidt, 2021), or already *published* (Biafora & Schmidt, 2020).

In an analogous manner, I adopted text excerpts, illustrations and tables from the manuscripts and harmonized them in accordance to my present thesis. The respective copyright owner granted reuse permission.

Contents

Abstract

A *double dissociation* impressively demonstrates that visual perception and visual awareness can be independent of each other and do not have to rely on the same source of information (T. Schmidt & Vorberg, 2006). Traditionally, an indirect measure of stimulus processing and a direct measure of visual awareness are compared (*dissociation paradigm* or *classic dissociation paradigm*, Erdelyi, 1986; formally described by Reingold & Merikle, 1988; Merikle & Reingold, 1990; Reingold, 2004). If both measures exhibit opposite time courses, a double dissociation is demonstrated. One tool that is well suited to measure stimulus processing as fast visuomotor response activation is the *response priming method* (Klotz & Neumann, 1999; Klotz & Wolff, 1995; see also F. Schmidt et al., 2011; Vorberg et al., 2003). Typically, observers perform speeded responses to a target stimulus preceded by a prime stimulus, which can trigger the same motor response by sharing consistent features (e.g., shape) or different responses due to inconsistent features. While consistent features cause speeded motor responses, inconsistent trials can induce response conflicts and result in slowed responses. These response time differences describe the *response priming effect* (Klotz & Neumann, 1999; Klotz & Wolff, 1995; see also F. Schmidt et al., 2011; Vorberg et al., 2003). The theoretical background of this method forms the *Rapid-Chase Theory* (T. Schmidt et al., 2006, 2011; see also T. Schmidt, 2014), which assumes that priming is based on neuronal feedforward processing within the visuomotor system. Lamme and Roelfsema (2000; see also Lamme, 2010) claim that this feedforward processing does not generate visual awareness because neuronal feedback and recurrent processes are needed. Fascinatingly, while prime visibility can be manipulated by visual masking techniques (Breitmeyer & Öğmen, 2006), priming effects can still increase over time. Masking effects are used as a direct measure of prime awareness. Based on their time course, *type-A* and *type-B masking functions* are distinguished (Breitmeyer & Öğmen, 2006; see also Albrecht & Mattler, 2010, 2012, 2016). Type-A masking is most commonly shown with a typically increasing function over time. In contrast, type-B masking functions are rarely observed, which demonstrate a decreasing or u-shaped time course. This masking type is usually only found under *metacontrast backward masking* (Breitmeyer & Öğmen, 2006; see also Albrecht & Mattler, 2010, 2012, 2016). While priming effects are expected to increase over time by Rapid-Chase Theory (T. Schmidt et al., 2006, 2011; see also T. Schmidt, 2014), the masking effect can show an opposite trend with a decreasing or u-shaped type-B masking curve, forming a double dissociation.

In empirical practice, double dissociations are a rarity, while historically simple dissociations have been the favored data pattern to demonstrate perception without awareness, despite suffering from statistical measurement problems (T. Schmidt & Vorberg, 2006). Motivated by this shortcoming, I aim to demonstrate that a double dissociation is the most powerful and convincing data pattern, which provides evidence that visual perception does not necessarily generate visual awareness, since both processes are based on different neuronal mechanisms. I investigated which experimental conditions allow for a double dissociation between priming and prime awareness. The first set of experiments demonstrated that a double-dissociated pattern between priming and masking can be induced artificially, and that the technique of induced dissociations is of general utility. The second set of experiments used two awareness measures (objective vs. subjective) and a response priming task in various combinations, resulting in different task settings (single-, dual-, triple tasks). The experiments revealed that some task types constitute an unfavorable experimental environment that can prevent a double dissociation from occurring naturally, especially when a pure feedforward processing of the stimuli seems to be disturbed. The present work provides further important findings. First, stimulus perception and stimulus awareness show a general dissociability in most of the participants, supporting the idea that different neuronal processes are responsible for this kind of data pattern. Second, any direct awareness measure (no matter whether objective or subjective) is highly observer-dependent, requiring the individual analysis at the level of single participants. Third, a deep analysis of priming effects at the micro level (e.g., checking for fast errors) can provide further insights regarding information processing of different visual stimuli (e.g., shape vs. color) and under changing experimental conditions (e.g. single- vs. triple tasks).

1. Introduction

The human brain, its neuronal architecture and functional mechanisms are fascinating, albeit very complex. Hence, many cognitive processes are not fully understood and there is a lot of ongoing research in neuroscience disciplines like psychology. The difficulty is, however, that cognitive processes cannot be observed directly (Dunn & Kirsner, 2003). This is why "their existence and function[s] must be inferred from the manner in which task performance changes from treatment to treatment" (Dunn & Kirsner, 2003, p. 1), sometimes in combination with modern measurement techniques such as fMRI[2] or EEG[3]. Thus, especially studies with brain-damaged patients[4] provide important findings in terms of cognitive functionality. Further, dissociations can help "to infer the existence of separate mental processes", which is the reason why some research disciplines "have placed increasing reliance on the logic of dissociations" (Dunn & Kirsner, 2003, p. 1). A *simple dissociation*[5] shows that a certain manipulation causes an increasing effect of a specific task while the same manipulation has no effect on another task (T. Schmidt & Vorberg, 2006). A *double dissociation*, in contrast, shows that a manipulation can have opposite effects on two different tasks. While the effects are increasing for task T_1, they are decreasing in task T_2 (T. Schmidt & Vorberg, 2006). Obviously, a double-dissociated data pattern is more powerful than a simple-dissociated one because the lack of effect in simple dissociations could be due to the possibility that the measure is not sensitive enough for this kind of manipulation and does not respond to it (Dunn & Kirsner, 2003). It is therefore plausible that some information remains undetected by this measure (T. Schmidt & Vorberg, 2006).

In studies of visual perception, a double dissociation provides strong evidence of two processes with different underlying (neuronal) mechanisms. The fact that a visual stimulus can affect behavior (e.g., causing fast priming effects that increase over time) while its visibility decreases, indicates that stimulus awareness and stimulus processing

[2] Functional magnetic resonance imagine.

[3] Electroencephalography.

[4] People who suffer from a lesion of a certain brain region or a limited functionality of specific brain areas.

[5] It should be noted, that *simple dissociation(s)* and *single dissociation(s)* describe the same phenomenon and are often synonymously used in the literature. For the sake of clarity, I will further use the term simple dissociation(s).

cannot be based on the same processes (T. Schmidt & Vorberg, 2006). In empirical practice, however, double-dissociated patterns are not easy to obtain since very specific experimental conditions must be met. Even if a double-dissociated data pattern can be obtained, researchers are often forced to defend this data pattern against criticism that it might be caused by some measurement artifacts (e.g., Peremen & Lamy, 2014). Furthermore, and although it has been shown that simple dissociations involve some measurement problems (T. Schmidt & Vorberg, 2006), this kind of data pattern still dominates the research landscape in visual science and is favorably used to demonstrate perception without awareness. Convinced that a double dissociation constitutes one of the most powerful data patterns, despite being rarely mentioned in the literature, I was motivated to study double dissociations in the field of visual perception. Due to the fact that double dissociations within this field are rarely demonstrated, and the shortcoming that their potential is not fully exhausted, one research question was whether a double dissociation can be induced artificially. For this reason, I will introduce the technique of induced dissociations, where systematically coupled variables can cause opposite effects on an indirect measure of stimulus processing and on a direct measure of awareness. Likewise, I was interested which experimental settings allow for a double dissociation between these two measures. Therefore, I further investigated whether a natural double-dissociated data pattern is observable, regardless of whether direct and indirect measures are applied together within the same trial (multiple task) or separately (single task). In addition, since some authors (e.g., Avneon & Lamy, 2018; Lamy et al., 2015, 2017; Peremen & Lamy, 2014) claim that objective and subjective measures of awareness are equally sensitive, I applied different types of direct tasks.

The theoretical part of my dissertation starts with the dissociation paradigm (Erdelyi, 1986; formally described by Reingold & Merikle, 1988; Merikle & Reingold, 1990; Reingold, 2004). The following figure (Fig. 1) intends to give an overview of the theoretical structure of the present thesis[6].

[6] The structure does not correspond to the exact sequence of topics within the present work.

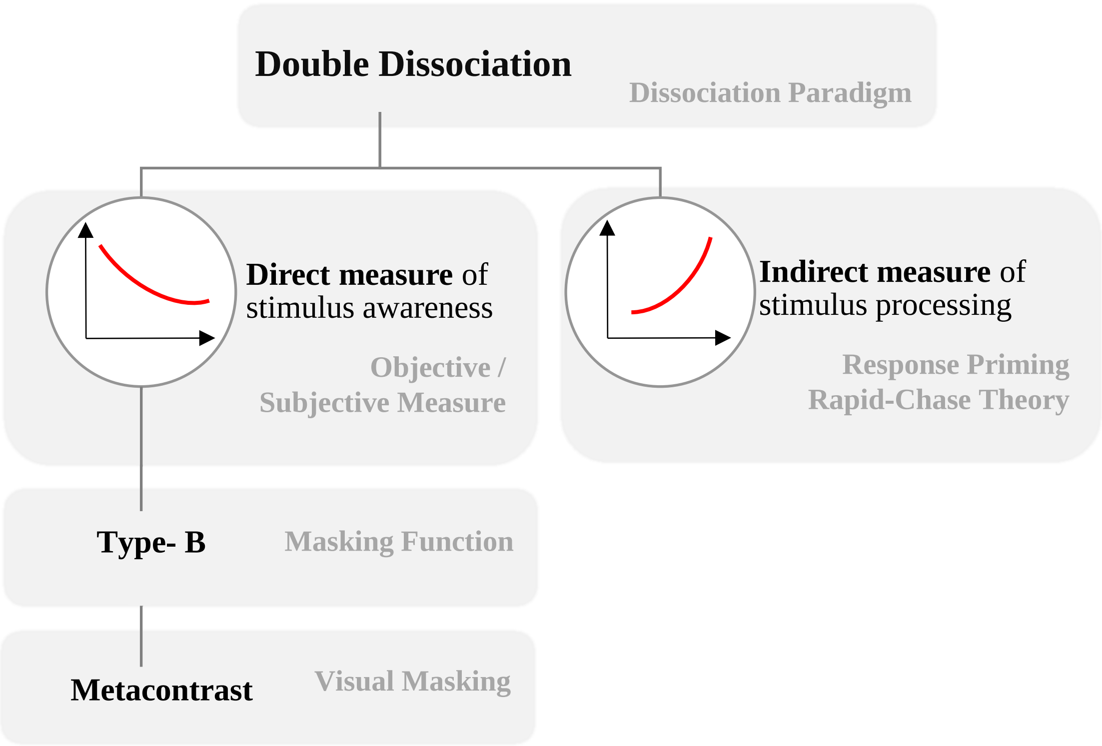


Figure 1. Structural overview of the theoretical part. In the dissociation paradigm (Erdelyi, 1986; formally described by Reingold & Merikle, 1988; Merikle & Reingold, 1990; Reingold, 2004), two types of measures are compared regarding their time course: a direct measure of stimulus awareness and an indirect measure of stimulus processing. If both direct and indirect measures exhibit opposite time courses, a double dissociation is demonstrated. In the present work, objective and subjective direct measures of stimulus awareness are implemented. In an indirect task, the response priming method is used, and the response priming effect is calculated for speeded keypress responses, serving as an indirect measure of stimulus processing. This priming effect is based on the assumptions of Rapid-Chase Theory (T. Schmidt et al., 2006, 2011; see also T. Schmidt, 2014). Under conditions of metacontrast as a technique of visual backward masking, the visibility of the stimulus can be manipulated, obtaining a decreasing or u-shaped type-B masking function. The time course of the masking effect serves as a direct measure of stimulus awareness. Accordingly, if the visibility of a visual stimulus decreases over time, exhibiting a type-B masking function, while priming effects increase as a measure of stimulus processing, a double- dissociated data pattern is demonstrated.

1.1 The classic dissociation paradigm

Several studies (e.g., Mattler, 2003; T. Schmidt et al., 2011; T. Schmidt & Vorberg, 2006; Vorberg et al., 2003) have demonstrated that a visual stimulus can affect behavior with measurable effects but simultaneously does not have to generate visual awareness. This is an extraordinary phenomenon, demonstrating that a stimulus and its information (e.g., color) is processed while there is no conscious perception of it. The time course of stimulus perception can be qualitatively dissociated from the time course of stimulus awareness. As noted, the dissociation paradigm (Erdelyi, 1986; formally described by Reingold & Merikle, 1988; Merikle & Reingold, 1990; Reingold, 2004)[7] is a suitable approach and often used in different research disciplines to show that two processes (e.g., visual perception and awareness) can be dissociated from each other. This paradigm is based on an indirect and a direct measure. According to Reingold and Merikle (1988; see also 1990), "perception without awareness can be demonstrated via a dissociation between …" a direct measure, which "indicate[s] the availability of stimulus information to awareness …" and an indirect measure, which "indicate[s] the availability of stimulus information, independent of whether or not this information is available to consciousness" (Reingold & Merikle, 1988, p. 563). In more detail, and in order to meet this requirement, an indirect measure of stimulus processing has to show some nonzero value, indicating that the visual information of the critical stimulus is processed, and in addition, some direct measure has to demonstrate a value at chance level. This *zero-awareness criterion* (T. Schmidt & Vorberg, 2006), however, places the burden on a researcher's shoulders to prove that a critical stimulus is out of awareness by showing chance performance of a direct measure (e.g., level of correct stimulus discrimination), while at the same time this stimulus affects behavior by measurable effects of an indirect measure (e.g., response priming effect). At first glance, this sounds trivial but even though an indirect effect can be produced easily, a simultaneous demonstration of null awareness is fairly difficult and often criticized as not convincingly showing chance discrimination (e.g., Eriksen, 1960; Holender, 1986; for more detailed information about the zero-awareness criterion see T. Schmidt & Vorberg, 2006). Furthermore, the zero-awareness criterion involves the challenge of verifying a null hypothesis of zero performance. Theoretically, this would be

[7] In contrast to the APA citation style, the sources are omitted in the following sections for better readability. Subsequently, the named authors are for reference.

no problem according to T. Schmidt and Vorberg (2006), since it could be solved by setting strict measurement criteria, “but binding standards of this sort have never been established in applied statistics or in the field of unconscious cognition …” (p. 489). Because of these methodological shortcomings, mostly concerning simple dissociations and the fact that “the controversy over perception without awareness is far from resolved” (Reingold & Merikle, 1988, p. 563), I was motivated to provide further evidence that a double dissociation between two measures is the most convincing data pattern to show that these two processes can be separated. For this reason, I will introduce the concept of T. Schmidt and Vorberg (2006) with criteria for unconscious cognition and the demonstration of simple- and double dissociations in Section 1.4 “Double dissociations”. The authors conclusively show that double dissociations can circumvent all these shortcomings of simple dissociations, and that a double dissociation is one of the most powerful data patterns to demonstrate that two processes can be independent of each other. The next chapter covers aspects of visual masking as a technique to manipulate the visibility of a stimulus, and thus the shape of the masking function in the direct measure.

1.2 Visual masking

Historically, visual masking has been used to investigate visual perception on a micro level. Early attempts mainly focused on the temporal perceptual process, for instance, the latency of retinal or cortical processing, or how long it will take for a stimulus to reach visual awareness. Still, techniques of visual masking are of great importance (Breitmeyer & Öğmen, 2006). In general, mask stimuli in studies of visual perception are used to manipulate the visibility of another visually presented stimulus, for instance a target[8] (Breitmeyer & Öğmen, 2006; see also F. Schmidt et al., 2011). Usually, stimulus visibility is viewed over target-mask SOA (*stimulus onset asynchrony*: time interval between the onsets of the stimuli) and serves as a direct measure of target awareness. Masks can be presented at different times within the stimulus sequence: simultaneously with the target stimulus (e.g., *common-onset masking*, Di Lollo et al., 1993; Bischof & Di Lollo, 1995; Di Lollo et al., 2000; Enns & Di Lollo, 2000), before the target (*forward masking),* or after the presentation of the target (*backward masking*, Breitmeyer & Öğmen,

[8] Usually, two terms are used to describe the ‘to be masked’ stimulus. While in studies on visual masking the term ‘target’ is used, response priming studies that include visual masking also use the term ‘prime’.

2006). Backward masking (see Fig. 2) is particularly used to study the temporal dynamics of visual processing for an interesting reason: Although the mask is visually presented *after* the target, the mask can still reduce the visibility of the target. The fact that judgements about a stimulus can be impeded even after this stimulus should be already processed, is of great interest (Duangudom et al., 2007). Metacontrast masking is a special type of backward masking that stands for itself: While most types of masking comprise masks that spatially overlap the target (e.g., pattern masks with structure or noise elements, see below), metacontrast masks achieve masking by sharing adjacent but non-overlapping contours with the target (Breitmeyer & Öğmen, 2006).

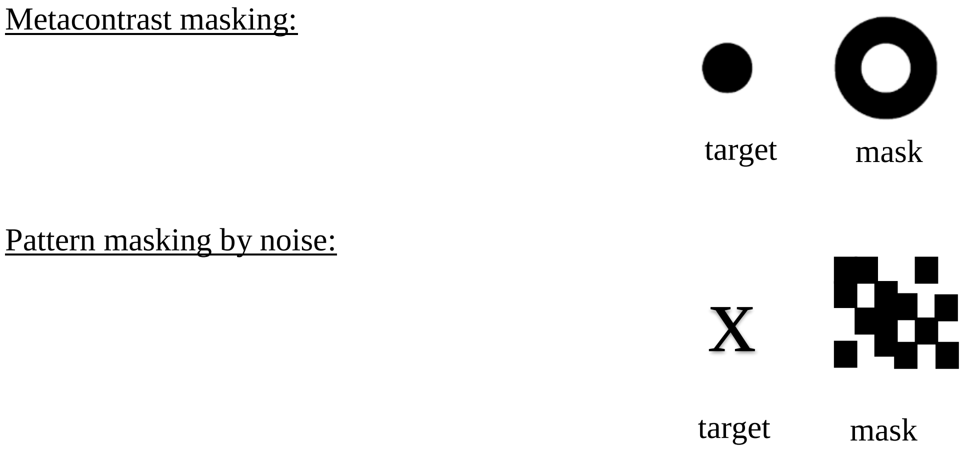


Figure 2. Different types of backward masking with a two-stimulus sequence. In metacontrast masking target and mask share adjacent but non-overlapping contours, while in pattern masking by noise target and mask spatially overlap. Stimuli are illustrated by Breitmeyer and Öğmen (2006, p. 33).

The mere fact that the mask reduces the visibility of the previously presented target without spatially overlapping it makes metacontrast an extraordinary masking technique. Even more interesting, when discrimination performances of the stimulus (used to assess its visibility) are plotted against SOAs, the resulting masking function can be decreasing or u-shaped under conditions of metacontrast (more details are provided in the next Section 1.2.1 “Masking functions”). Noteworthy, masking functions usually increase over time, while a decreasing or u-shaped masking function is only demonstrated under conditions of metacontrast (Breitmeyer & Öğmen, 2006; see also Albrecht & Mattler, 2010, 2012, 2016). There are several theories about metacontrast masking and attempts to explain why this characteristic pattern is obtained only by this kind of backward masking.

I have chosen some of these theoretical approaches, which will be explained in Section 1.2.2 “Theoretical approaches and empirical findings”. While metacontrast masking techniques are characterized by the presentation of a visual stimulus surrounded by a mask (e.g., a disc surrounded by a annulus), other methods of masking (e.g., *sequential blanking,* Mayzner & Tresselt, 1970; Mewhort et al., 1978) can yield effects of metacontrast as well (Breitmeyer & Öğmen, 2006). This indicates that metacontrast is not a trivial phenomenon.

In this work, I intend to show that a critical stimulus information, such as color or shape, can be visually processed although an awareness measure suggests that the observer is not aware of this color- or shape information. Metacontrast masking is an excellent tool for this purpose: The visibility of the stimulus (i.e., awareness) can be manipulated, most likely forming a decreasing or u-shaped time course while the processing of stimulus information is not affected, showing an increasing effect. Such a double dissociation strongly suggest that visual processing of a critical stimulus information (e.g., color or shape), and the conscious perception of this stimulus information can be based on different (neuronal) processing mechanisms (T. Schmidt & Vorberg, 2006). Actually, several studies have demonstrated that visual stimulus information can be unavailable to awareness because of masking, while motor- or cognitive processes were nonetheless influenced by this visual information (e.g., Eimer & Schlaghecken, 1998; Klotz & Neumann, 1999; Klotz & Wolff, 1995; Mattler, 2003; Merikle & Joordens, 1997; F. Schmidt & Schmidt, 2010; T. Schmidt, 2000, 2002; Vorberg et al., 2003).

1.2.1 Masking functions

In general, two types of masking functions can be observed: *type-A* and *type-B* (Kolers, 1962; Breitmeyer & Öğmen, 2006; see also Albrecht & Mattler, 2010, 2012, 2016). They are described as a function of target-mask SOA. Most commonly and typically observed is the type-A masking function, where stimulus visibility is lowest at short SOAs, then increases, and finally reaches its highest point at the longest SOAs. In a typical backward masking experiment, the mask is presented after the target stimulus, which is often very briefly presented (for some milliseconds, ms). Thus, the target signal is often weaker than the mask signal, while masking is strongest at short SOAs and decreases with increasing target-mask SOA. The typical time course of type-B masking is rarely demonstrated, and usually only found under conditions of metacontrast (Breitmeyer &

Öğmen, 2006; see also Albrecht & Mattler, 2010, 2012, 2016). Here, stimulus visibility is good when the mask immediately follows the target at short SOAs or at long SOAs, whereas visibility at intermediate SOAs is poor. In practice, the amount of masking (or stimulus visibility) is measured by a direct task. Hence, the observer might be asked to detect, discriminate, identify or categorize the stimulus; or the observer is asked to evaluate some stimulus characteristics (e.g., color, shape, brightness, etc.) or the stimulus as a fusion of all these features on a rating scale (F. Schmidt et al., 2011).

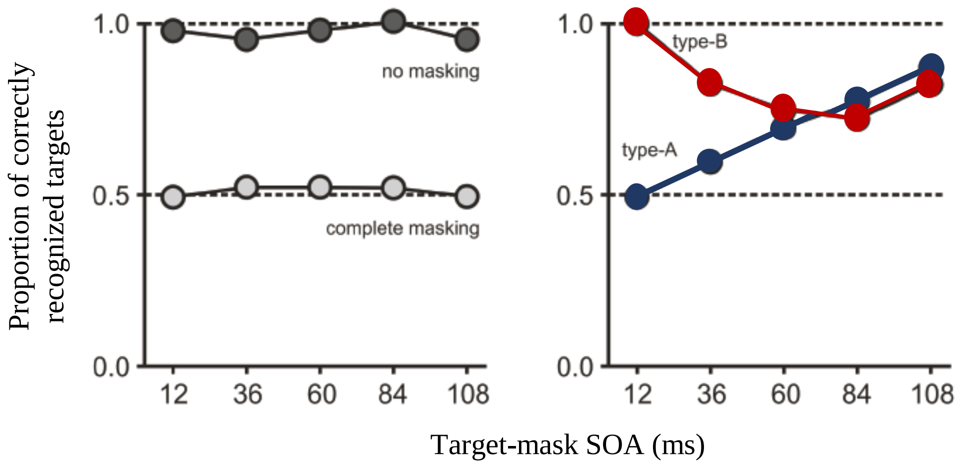


Figure 3. Fictitious data patterns of masking functions originally illustrated by F. Schmidt and colleagues (2011, p. 124). When no mask is presented (‘no masking’, dark grey, left panel), the stimulus can be correctly identified in 100% of trials. Under ‘complete masking’ (light grey, left panel), stimulus identification performance drops to chance level of 50% correct responses. The right panel shows typical patterns of type-A and type-B masking functions. Type-A masking is strongest at shorter SOAs and decreasing with increasing SOAs (dark blue, right panel). In contrast, the type-B masking function (red, right panel) shows the characteristically u-shaped pattern, strong masking at intermediate SOAs, weaker masking at shorter and longer SOAs. For demonstration purposes, colored highlights and axis labels have been adapted to this illustration.

Whether a type-A or type-B time course is observable depends on various factors (F. Schmidt et al., 2011); to name just a few: (1) properties of the stimulus such as the duration and intensity of the mask (or target), considered through their product, namely mask energy (Breitmeyer & Öğmen, 2006; see also Aydin et al., 2021)[9], (2) the stimulus

[9] In the metacontrast study of Aydin et al. (2021), a change in mask polarity led to a change in the masking functions: The same polarity of the ‘to be masked’ stimulus and the mask caused type-B masking, whereas under opposite polarity conditions a type-A masking function was obtained.

onset asynchrony, SOA (*onset-onset law*, Kahneman, 1967), (3) individual differences of the observers (e.g., *criterion content*, Kahneman, 1968; see also Albrecht et al., 2010; Albrecht & Mattler, 2012, 2016), and (4) stimulus size and orientation (Bridgeman & Leff, 1979; see also Duangudom et al., 2007). Fascinatingly, by modifying these or other factors (e.g., background intensity, number of stimulus elements, etc.) with different techniques of masking, impressive visual illusions can be achieved. In the following, I will describe some illusions, which show that even apparently small changes in the number of stimulus elements, in timing, or the spatial arrangement of physical stimuli can lead to a qualitative change in the visual perception of the observer. The examples show in an impressive manner that perception of the environment is diverse and multifaceted.

In a study of Macknik and Livingstone (1998) they masked a pair of isolated bars of different length with two non-overlapping flanking bars of the same length. They found an illusory effect called the *standing wave of invisibility*[10], which was strongest when both stimuli were flickered cyclically in alternation with different durations. According to Macknik and Livingstone (1998), this illusion where the target (pair of isolated bars) is continuously masked "probably occurs because every occurrence of the mask strongly forward-masks the subsequent target … and strongly backward-masks the previous target …" (p. 146 f). As a result, only the two flanking bars (mask) are perceived, while the isolated bars (target) appear to be absent for the observer. "However, the most critical feature of the SWI [Standing Wave Illusion] is not the cycling per se …" (Macknik & Martinez-Conde, 2008, p. 141), but forward and backward masking are optimally combined; and according to Macknik and colleagues (Macknik & Livingstone, 1998; Macknik et al., 2000; Macknik & Martinez-Conde, 2004, 2008) most accurately explained by lateral inhibition circuits within the visual system[11].

[10] This description might reflect the neuronal pattern of single unit recordings of neurons in area V1 of an alert rhesus monkey. The response dynamics of this neuron shows some strong response (approx. 200 spikes/s) at the time the mask stimulus is presented. However, within the period where the mask and target stimuli were presented cyclically to receive optimal forward and backward masking (mask-target-mask), it appears like a standing wave of neuronal responses (on average approx. 30-50 spikes/s).

[11] The lateral inhibition model will be explained in Section 1.2.2 "Theoretical approaches and empirical findings".

Herzog and Koch (2001) used similar stimuli and demonstrated that two visual phenomena known as *feature inheritance* or *shine- through effect* (Fig. 4) are strongly influenced by temporal and spatial stimulus properties.

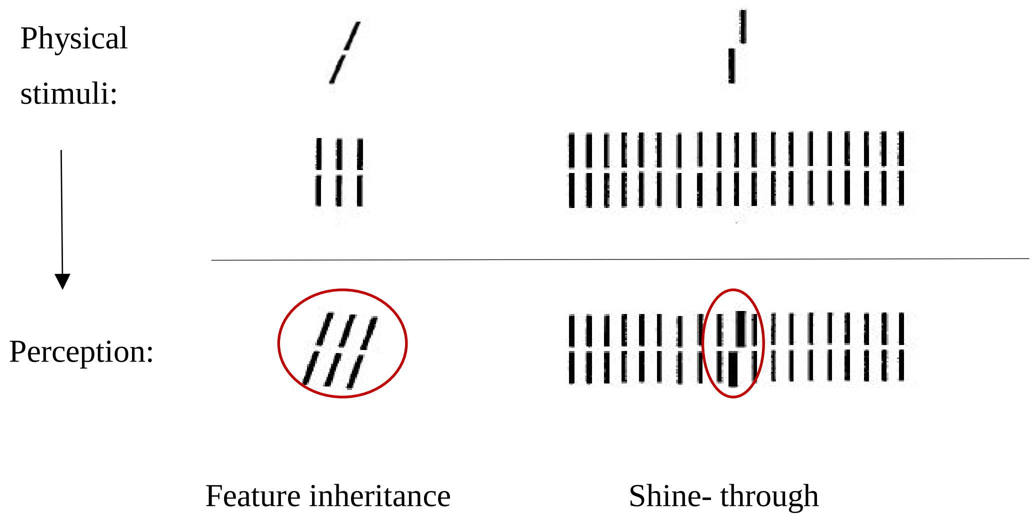


Figure 4. Physical stimuli and perception of the visual phenomena feature inheritance and the shine-through effect. Adapted from Herzog and Koch (2001, pp. 4272, 4274).

While the shine-through effect seems to prevail with a larger number of gratings, feature inheritance seems more strongly when the number of elements is small (Breitmeyer & Öğmen, 2006). Interestingly, if the presentation time was shortened by 10 ms (compared to the standard conditions of the experiment), shine-through was not observable (Herzog, Fahle, & Koch, 2001). Furthermore and based on the findings of Herzog, Koch and Fahle (2001), both effects seem to operate on a different time scale. While most observers perceive shine-through when the target is presented for 20 ms, observers need a longer presentation time to perform feature inheritance. As assumed by the authors, this might be a sign of feature separation in case of the shine-through effect, and a sign of feature binding in case of feature inheritance. Therefore, timing seems to be crucial for these effects[12]. As noted by Herzog et al. (2001), taking into account the findings of Di Lollo et al. (2000) that "segmentation may require recurrent neuronal connections …" (p. 2344),

[12] Interestingly, later findings of Herzog (2007) demonstrated that by changing the spatial layout of a mask (more flanking lines), type-B masking functions can change to type-A masking functions or flat masking functions.

models focusing on local processing (e.g., lateral inhibition) could not be able to explain the results (Herzog, Koch, & Fahle, 2001).

These examples demonstrate in a simple manner one of the most fundamental differences in historical approaches to describe visual information processing and masking. While some theories are based on the unidirectional option of mostly feedforward processed mechanisms (models of lateral inhibition, e.g., Macknik and coworkers, 2000; 2004, 2008; or Weisstein and colleagues, 1968; 1975); more recent neuroanatomical and physiological evidence has emerged providing models of reentrant feedback processing, reflecting the idea that “communication between two brain areas that are connected to each other is seldom one-way” (Di Lollo et al., 2000, p. 482; see also Lamme et al., 1998, 2002; Lamme & Roelfsema, 2000; Fahrenfort et al., 2007; Felleman & Van Essen, 1991). In the next chapter, I will start with some of the first discoveries of masking effects, which led to prominent theories and models of (metacontrast) masking.

1.2.2 Theoretical approaches and empirical findings

At the beginning of the twentieth century, Stigler (1910) was one of the first who referred to the effect of metacontrast. Based on his investigations on visual sensations, he assumed that the perception of a stimulus is shaped by a *Primärempfindung* [primary sensation], which consists of an initial and a trailing part. The initial part of this visual sensation is produced by the presence of the stimulus and is called *homophotisches Bild* [homophotic image]. The trailing part of this visual sensation outlasts the stimulus and is called *metaphotisches Bild* [metaphotic image], corresponding to Exner’s notion (1868) of a *positives Nachbild* [positive after-image] (Stigler, 1910). Stigler (1910) called it *Metakontrast* [metacontrast], since he demonstrated that the metaphotic image of a stimulus can be affected by the homophotic image of another stimulus. In line with Exner, Stigler (1910) assumed that the metacontrast effect is most likely mediated by inhibition of the horizontal cells in the retina. Later, Fry (1934) varied the time intervals between two stimuli (flash of light). While the duration of the first stimulus was kept constant, the duration of the second stimulus was varied, however, producing a sensation equally bright as produced by the first stimulus. Based on his observations, Fry (1934) concluded “that the response of the retina to the first stimulus is considerably delayed and prolonged and overlaps in time the response to the second stimulus and is inhibited by it [the second one] by some kind of interaction between retino-cortical pathways …” (p. 706). According to

Breitmeyer and Öğmen (2006), the first person who referred to the typically shaped metacontrast masking function was Alpern (1953, as cited in Breitmeyer & Öğmen, 2006, p. 16). He inferred from his findings, that metacontrast is most likely a retinal phenomenon based on inhibitory interactions between fast cone and slow rod processes. Since metacontrast effects may not only result from the suppression of the target's contours by *contour suppression*, but also from a suppression of the bounded area of the target, Stoper and Mansfield (1978) called this type of masking *area suppression*; however, pointing to the fact that their explanation is limited to specific experimental conditions under metacontrast. Still, prominent optical illusions such as the *Mach bands* (Mach, 1865) and the *grid illusion* of Hering (1878) and Hermann (1870) are used as examples of lateral inhibition and as neural mechanism to exaggerate contrast (Breitmeyer & Öğmen, 2006; see also von Békésy, 1968).

Beyond these early findings, several theories of backward masking[13] and models of type-B masking exist which provide an empirical framework for these visual phenomena. In the classical work of Breitmeyer and Öğmen (2006) *Visual Masking. Time Slices Through Conscious and Unconscious Vision*, they provide an overview of the most common approaches on metacontrast, further indicating that although most models adequately explain metacontrast, some quantitative descriptions and simulations of early models make incorrect predictions due to the limited power of computational technology.

> Although many models can generate the basic U-shaped function, they fail to generalize when the effects of other variables, such as background luminance or color, on masking functions are considered. While some experimental findings can be handled by parametric variations … double dissociation phenomena between the visibility and masking effectiveness of a stimulus are critical in testing models because they put very strong constraints on mechanisms and processes … .(Breitmeyer & Öğmen, 2006, p. 139)

[13] Although not specially adapted to the technique of metacontrast where masks do not spatially overlap with the 'to be masked' stimulus.

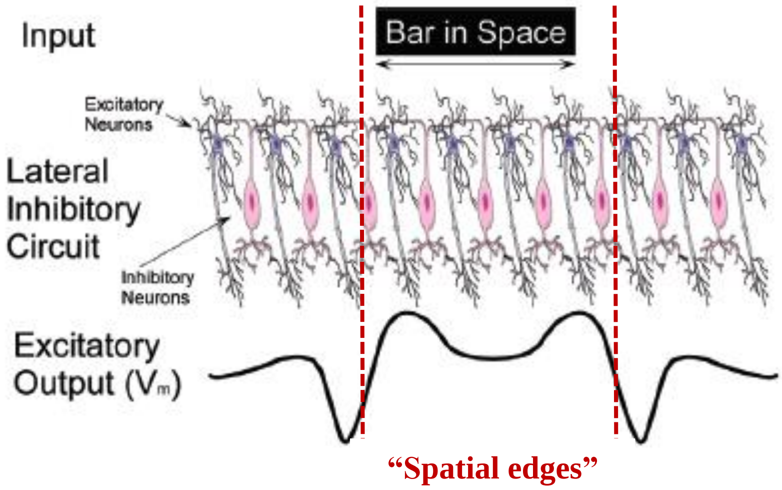
Regarding these shortcomings, I will limit myself to the basic ideas of prominent approaches while neglecting mathematical models. Furthermore, I will strongly focus on theories supporting the idea that two types of neuronal processes, feedforward processing and recurrent feedback mechanisms are involved in the human visual system. There are several reasons for this theoretical limitation. First, this corresponds to neurophysiological findings that a specific brain area, which sends signals to another brain area will also receive feedback from it via recurrent pathways (Felleman & Van Essen, 1991; see also Bullier, 2001; Di Lollo et al., 2000). Moreover and second, latest research assumes that within this processing cycle, this later phase of neural (feedback) activity is associated most strongly with conscious perception, i.e., visual awareness (Di Lollo et al., 2000; see also Lamme, 2010). Third, because speeded visuomotor responses are an essential part of this work, time-based neural processes such as feedforward activation and feedback mechanisms are indispensable. Fourth, Rapid-Chase Theory (T. Schmidt et al., 2006, 2011; see also T. Schmidt, 2014) as part of the theoretical framework represents the idea that stimulus information is processed in a feedforward manner and a fast visuomotor response activation, as observable under response priming, is assumed to be based on feedforward processing. The conscious perception of that stimulus information (e.g., shape), in contrast, can be manipulated by masking since it is assumed that visual awareness needs an additional second process – the so-called feedback. Fifth and last, the most basic assumption of a double-dissociative data pattern (e.g., between the processing of stimulus information and stimulus awareness) that it must be based on two separate processing mechanisms, takes for granted an approach which refers to at least two different channels. Due to the fact that most theories were specifically designed for visual masking phenomena only, I will refer to those theories with the best link for a double dissociation between priming and masking and furthermore to those approaches which coincide with previous findings of our research group.

Therefore, single-channel models (e.g., Bridgeman's model based on recurrent lateral inhibition, 1971; Francis's extension of the *boundary contour system* (BCS), 1997, see also 2000; originally proposed by Grossberg & Mingolla, 1985a, 1985b)[14] and the dual-process *perceptual retouch* (PR) model by Bachmann (1984, see also 1997) which includes recurrent lateral inhibition, will not be included. Due to rational considerations, and despite being one of the first models which can explain u-shaped masking functions and handle parametric variations (Breitmeyer & Öğmen, 2006), Weisstein's *two-factor neural network model* (1968, 1972; modified model by Weisstein, Ozog, & Szoc, 1975) will be neglected, because it would require some add-on hypothesis for double-dissociated processes.

Most theories are based on the response dynamics of neurons to explain metacontrast and masking effects. For instance, Macknik and colleagues (Macknik et al., 2000; Macknik & Martinez-Conde, 2004, 2008) found that the *spatiotemporal edges* (see Fig. 5) of the mask were most important to suppress the perception of the target. This was related to their findings that first, the spatial edges of the target were "most important to convey its visibility …", and second that the target's neuronal onset and termination (i.e., temporal edges) seem to provide "the strongest signal concerning the target's visibility" (Macknik & Martinez-Conde, 2004, p. 776). Temporary bursts of spikes that occurred immediately after the stimulus turned on (onset-response) and off (after-discharge) act as neural correlates. Metacontrast effects are explained by mechanisms of feedforward lateral inhibition, since the stimuli have no overlapping contours. The neuronal responses to the spatiotemporal edges of the mask are able to inhibit the neural responses to the spatiotemporal edges of the target (Macknik & Martinez-Conde, 2004, 2008).

[14] According to Breitmeyer and Öğmen (2006) the BCS relies on the cortical P pathway. Therefore, the mechanisms can be considered to operate on a single channel. Nevertheless, the extended model incorporates excitatory feedforward and feedback, as well as feedforward inhibition and inhibitory feedback.

a)



b)

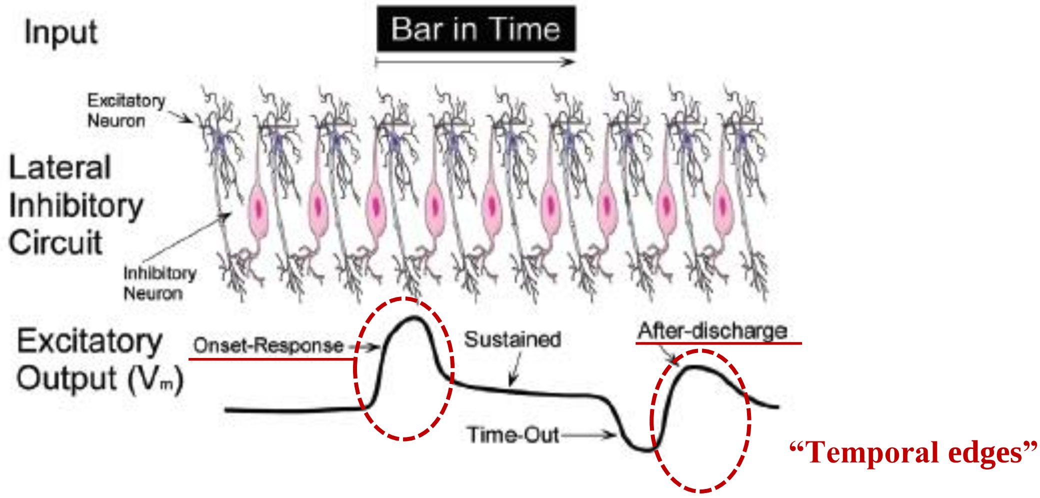


Figure 5 a) Model of the spatial lateral inhibition model proposed by Hartline and Ratliff (Ratliff, 1961, as cited in Macknik & Martinez-Conde, 2008, p. 131; Ratliff et al., 1974). Excitatory neurons receive visual input. This excitatory input is transmitted laterally as inhibition to induce edge enhancement. **b)** Two neurons (excitatory and inhibitory, respectively) show several neuronal response phases over a period of time, which represent the temporal edges of the visual stimulus. Adapted illustration from Macknik and Martinez-Conde (2008, p. 131).

Although Macknik and Martinez-Conde (2008) argue "that [the] after-discharge timing varies as a function of stimulus termination …", and thus cannot be "caused by feedback from the stimulus's onset" (p. 127), I included their model, because it highlights the importance of the late (second) neuronal response for backward masking.

The original version of the *dual channel model* by Breitmeyer and Ganz's (1976) suggest that each visual stimulus activates a fast transient channel and a later, more sustained one. Hence, the temporal delay of target and mask during backward masking causes a temporal overlap of those channels, which leads to the masking effect (Macknik & Martinez-Conde, 2008; see also Breitmeyer & Öğmen 2000, 2006; Öğmen et al., 2003). In 2006, Breitmeyer and Öğmen revised this model by the predictions of the *retino-cortical dynamics* (RECOD) model by Öğmen (1993), that now the magnocellular and parvocellular pathways were considered as neural correlates for the transient and sustained channels, respectively (Öğmen et al., 2003; Breitmeyer & Öğmen, 2006). More precisely, "the model postulates that the visibility of the target is correlated with the activities in post-retinal areas receiving their main input from the sustained … pathway" (Öğmen et al., 2003, p. 1339) and that the real-time dynamics of the sustained channel has different phases (see also Purushothaman et al., 1998 for a detailed illustration of the phases). This sustained pathway is considered to have an important part within the feedback system, as noted by Breitmeyer and Öğmen (2006): "The initial peak response corresponds to the feedforward-dominant phase", while "the decay of the activity to a lower plateau allows the feedback signals to dominate …" (Breitmeyer & Öğmen, 2006, p. 170; see also Öğmen et al., 2003). Hence, under conditions of backward masking, the mask's neuronal response spreads through the fast transient channel, while the neuronal response to the target has already passed it and is already about to activate the slower and sustained channel (Macknik & Martinez-Conde, 2008). Since the mask is presented later in time, the fast transient channel of the mask and the slower sustained channel of the target interact through *inter-channel inhibition* (*transient-on-sustained inhibition*, Öğmen et al., 2003; Breitmeyer & Öğmen, 2000, 2006). Furthermore, the slower sustained activity of the target and mask interact via *intra-channel inhibition* (Öğmen et al., 2003; *sustained-on-sustained inhibition*, Breitmeyer & Öğmen, 2006, 2000), where the lower plateau of the target's sustained activity with its feedback-dominant phase is most affected.[15] Hence, target visibility is reduced by inhibition processes (see Fig. 6).

[15] Breitmeyer and Öğmen (2006) describe an additional third mechanism, which is only assumed for spatially overlapping target and mask stimuli (e.g., masking by structure or noise). Then, "mask sustained activity can integrate with target sustained activity via the sharing of common retinotopically organized pathways" (Breitmeyer & Öğmen, 2006, p. 166), a process called *intra-channel integration*. This could contribute to the masking effect in forward as well as in backward masking.

Since the RECOD model (Breitmeyer & Öğmen, 2006; original model from Öğmen, 1993) is based on two separate pathways with different latencies, it allows for a dissociation between fast motor responses and target visibility (i.e., visual awareness).

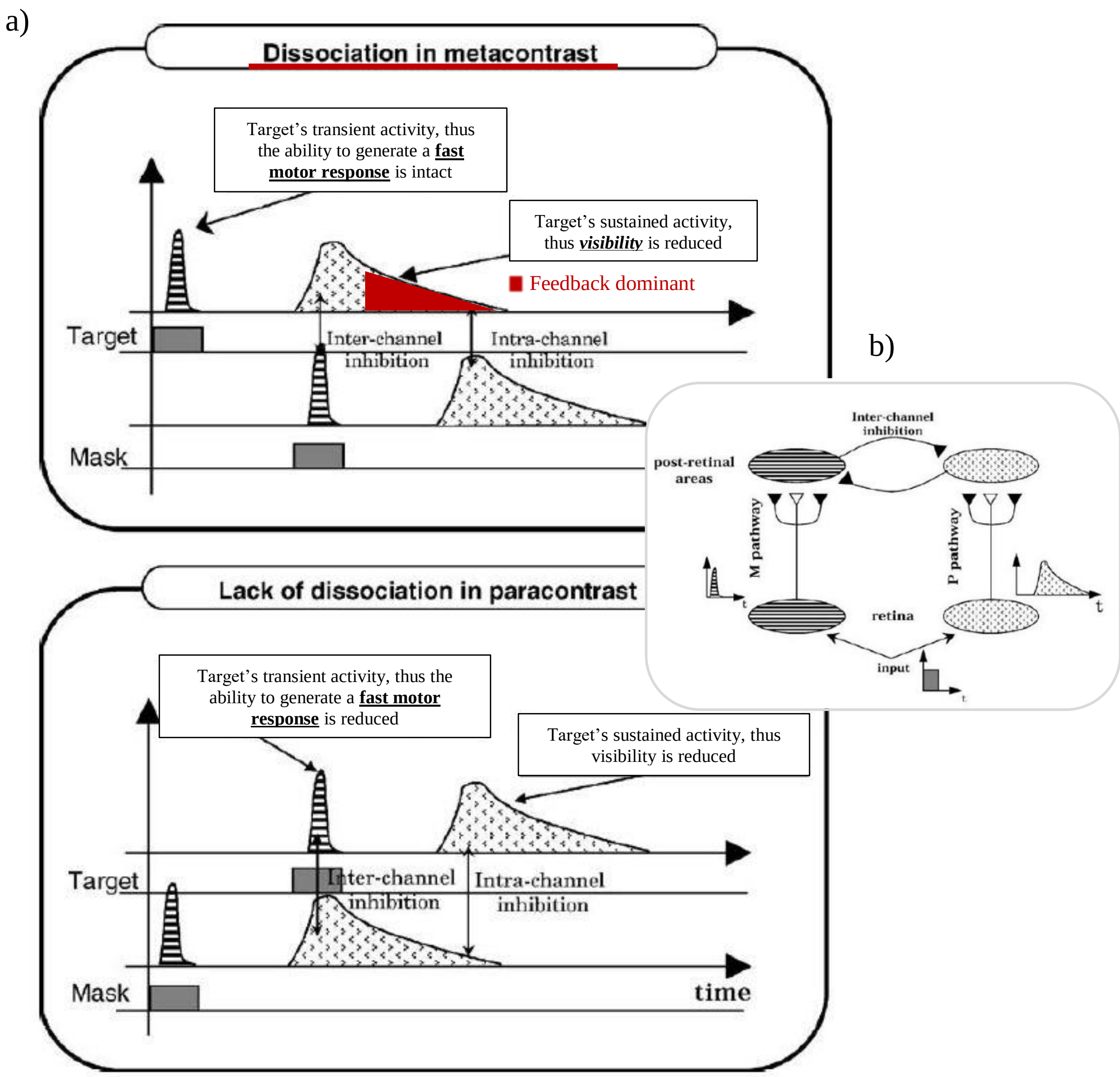


Figure 6 a) Predictions of the RECOD model during backward metacontrast masking (top panel) and forward paracontrast masking[16] (lower panel). The illustration demonstrates the double dissociation between fast motor responses to the target and its reduced visibility (i.e., visual awareness) during metacontrast masking. **b)** Schematic illustration of the model. Triangular symbols represent inhibitory (filled) and excitatory synapses in both pathways. Adapted illustrations of Öğmen et al. (2003, p. 1338 f).

[16] Similar to metacontrast masking, paracontrast masking is a special type of forward masking where the mask shares adjacent but non-overlapping contours with the target.

Most of these model predictions are in line with the findings of Lamme and colleagues (Lamme et al., 2002; Lamme & Roelfsema, 2000; Lamme et al., 1998; see also Fahrenfort et al., 2007). They assume, that the onset-responses are based on feedforward processing, but that the "late responses [similar to Macknik and colleagues' after-discharge] are due to recurrent feedback" (Macknik & Martinez-Conde, 2008, p. 129). Physiological recordings in awake (Lamme et al., 2002) and anesthetized macaque monkeys (Lamme et al., 1998) with figure-ground stimuli suggest that local information about the figure-ground scene (e.g., the orientation of the elements) is carried by an early neural activity, corresponding to low-level processing. Lamme and colleagues (e.g., 1998, 2002) found that this activity remained present when the animals were anesthetized and that it was unaffected by masking. The neural activity, which occurred later seems to be related to high-level processing such as figure-ground modulation (FGM) and was affected by these factors (Lamme et al., 2002). In a recently published study by Kirchberger et al. (2021; see Schnabel et al., 2018 with similar stimuli but without task performance of the animal) they used optogenetic silencing for neurons in higher visual areas (HVAs) in mice and found that feedback from HVAs is inhibited, leading to a reduced late V1 response, while the early peak of V1 responses was not systematically influenced by inhibition. Hence, Lamme and colleagues (Lamme et al., 2002; see also Kirchberger et al., 2021) assume that visual perception and the conscious report about this percept (i.e., visual awareness) has several stages. While elementary features are analyzed in a first feedforward process, recurrent processes combine these features into objects within the next stage and a conscious report could be possible (Lamme et al., 2002). Visual information is assumed to be processed via two streams[17], from low-level to high-level areas via feedforward connections, and back via feedback connections. The *dorsal* pathway (magnocellular-dominated) starts at V1, goes through the visual area V2 and MT[18] to the parietal cortex, while the parvocellular-dominated *ventral* route starts at

[17] While Milner and Goodale (1995) describe these two pathways with distinct functions, the findings of T. Schmidt (2002) contradict the idea of ventral and dorsal cortical streams with separate functions. The assumption that the ventral cortical stream is responsible for color processing and may give rise to awareness, while visuomotor processes seem to be controlled by the dorsal stream, is at odd with his findings that "color stimuli blocked from awareness by visual masking …" can trigger "fast motor responses" (T. Schmidt, 2002, p. 112).

[18] Middle temporal area.

V1, then goes via V2 and V4 to the inferior temporal cortex (IT cortex). During backward masking, the target activates an early wave of neural feedforward processing, triggered via the cell-to-cell activation from lower to higher visual areas. This target processing is completed before recurrent feedback processes of the same stimulus are sent back to lower levels. At the time when the target's feedback signals of the higher areas reach the lower levels, information at these levels consist of the mask that interrupts or "clashes" with the feedback signals from the target (Lamme & Roelfsema, 2000).

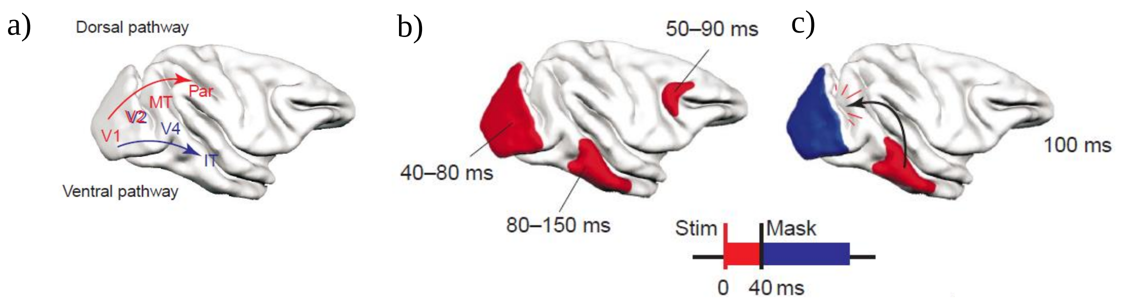


Figure 7 a) MRI image of macaque monkey cortex with the dorsal and ventral pathways of the visual system. **b)** Neural activity evoked by a visual stimulus (lasting 40 ms, red bar), which is followed by a mask (blue bar). Latencies of response intervals of the first stimulus are shown in red for the areas V1, frontal eye field (FEF) and IT. **c)** The mismatch of recurrent information and feedforward information can be used as explanation for the masking effect. Feedback signals from higher visual areas equipped with the stimulus information from the first stimulus (e.g., target, red bar) and may "clash" with the (feedforward) responses of the second stimulus (e.g., mask, blue bar) in lower visual areas. Illustrations by Lamme and Roelfsema (2000, pp. 572, 577).

Another technique of masking, which suggests a contributory role of reentrant activity as well, is common-onset masking (e.g., Di Lollo et al., 1993; Bischof & Di Lollo, 1995; Di Lollo et al., 2000; Enns & Di Lollo, 2000). Here, a target and mask stimulus are simultaneously displayed (common-onset), but the mask remains on screen for durations up to several seconds after the target turned off. According to Di Lollo et al. (2000) metacontrast masking is most similar to common-onset masking, since the procedures for obtaining masking are the same for both types. However, as noted by the authors (2000), most "inhibitory models [on metacontrast masking] cannot account for common-onset masking, because they were designed to exclude the possibility of masking when the target and mask are presented simultaneously" (p. 484). Therefore, Di Lollo and colleagues (2000) use the term *masking by object substitution* (Enns & Di Lollo, 1997, 2000; see also

Di Lollo et al., 2000)[19]. This type of masking includes the idea that at low-level areas, a visual stimulus is encoded and then passed on to higher levels. Via reentrant processing, higher levels receive confirmation of the visual input from lover areas. This "confirmation mechanism" helps to ensure that the stimulus is correctly represented at higher levels. During common-onset masking, the initial display of target and mask is replaced by the display of the mask alone, because the required confirmation mechanisms have not taken place to confirm the initial display (target and mask). Thus, the changed visual input (mask alone) replaces the percept of target and mask (Di Lollo et al., 2000). The authors refer to the ERP (event-related brain potential) findings of Luck and colleagues (Luck et al., 1994) as neurophysiological evidence for the timing of this reentrant process, because the pattern of activation would have indicated that reentrant pathways completed a global feedback loop (Di Lollo et al., 2000).

Likewise, further studies with different neurophysiological methods support the idea that the late neuronal responses are crucial for the masking effect in backward masking, and further for a conscious report of perception. According to the magnetoencephalography (MEG) results from van Aalderen-Smeets, Oostenveld, and Schwarzbach (2006) early latency MEG components and masking functions are not correlated, strongly indicating that early visual areas cannot be involved in (metacontrast) masking. Additionally, Bridgeman's (1975, 1980) single unit recordings from cat and monkey visual cortex demonstrated that the masking effect was associated with a reduction in the late peak of the V1 responses. He (Bridgeman, 1980) concluded that the late components are more responsible for perceptual phenomena such as metacontrast effects in humans and further that reentrant signals return to the cortex after they have been

[19] According to the authors (Di Lollo et al., 2000), spatiotemporal aspects can be ruled out as explanation for several reasons. Mechanisms of feedforward inhibition are based on the onsets of the stimuli. Therefore, temporal aspects such as the 'on' transients of the stimuli cannot explain the masking effects due to the common-onset of both stimuli. Furthermore, explanations based on the 'off' transients are also unsatisfactory, because transient neural bursts triggered by the offset of the target only reduce mask's visibility. Additionally, the use of a four-dot mask falling at the corners of the target is supposed to have not enough contours to account for interactions of lateral inhibition. Nevertheless, using a four-dot mask, "a critical link between spatial attention and object substitution …" was found, for instance whenever "spatial attention could not be easily focused on the target" (Di Lollo et al., 2000, p. 496). For instance when a larger number of target elements was used.

processed in other brain areas.[20] Even more impressive are the findings with transcranial magnetic stimulation (TMS). In the study of Walsh and Cowey (1998), subjects were unable to detect visual stimuli letters when magnetic pulses were applied between 80 and 100 ms after stimulus onset. Within this time window, the fast feedforward signal should have reached higher brain areas, and recurrent feedback signals should return to lower brain areas (Lamme & Roelfsema, 2000), indicating once more the relevance of feedback processes for visual awareness (Lamme & Roelfsema, 2000; see also Ro et al., 2003).

Further conclusions can be drawn from the fMRI study by Haynes, Driver and Rees (2005) with their honeycomb-like stimuli applied as targets and metacontrast mask. They found that the activity in higher visual areas (compared to the activity in the early visual cortex) was better correlated with the effect of metacontrast masking. Based on their findings, they concluded "that activity in early visual cortex may be necessary for visibility of fundamental features such as brightness …", but that "the level of activity in early areas alone may not always be sufficient to explain visibility" (Haynes et al., 2005, p. 818). Since it was not clear, whether this correlation was caused by feedforward or backward signals, their findings must be evaluated in relation to results of studies with other neurophysiological methods.

1.3 Response priming

As mentioned, perception without awareness is best represented with a double dissociation of two measures, where the data pattern demonstrates that the stimulus information has been processed without generating visual awareness. One commonly used method to demonstrate stimulus processing as fast visuomotor responses is a special form of priming, known as response priming[21] (Klotz & Neumann, 1999; Klotz & Wolff, 1995; see also F. Schmidt et al., 2011; Vorberg et al., 2003).

[20] According to Di Lollo et al. (2000), the far wider spatial distribution of the late activity in primary cortex strongly support the idea of a reentrant origin of this signal, since "it is now known that … the spatial distribution of the reentrant fibers is far wider than that of the corresponding ascending units" (Di Lollo et al., 2000, p. 503).

[21] Note that already in the early sixties, Fehrer and Raab (1962) reported experiments with speeded keypress responses in the context of visually masked stimuli and their visuomotor effects. Twenty years later, Rosenbaum and Kornblum (1982) investigated motor responses and called their method *response priming*.

Most typical for response priming studies is the situation where participants react via keypress responses (also pointing movements, T. Schmidt, 2002; T. Schmidt et al., 2006; T. Schmidt & Schmidt, 2009; in combination with EEG, Eimer & Schlaghecken, 1998; Vath & Schmidt, 2007) as fast and as accurately as possible to a visually presented target stimulus. Usually, the target follows a visually presented prime stimulus. Prime and target can share the same stimulus features (e.g., shape, color, or orientation) in consistent trials, or they can be different regarding their stimulus features in inconsistent trials. In the first case, faster motor responses occur due to similar stimulus features, and the fact that the prime as first visual input activates the response assigned to it, while the target can continue this motor response (e.g., T. Schmidt, 2002). In inconsistent trials, different stimulus features of prime and target lead to slower motor responses, caused by a response conflict of the initially activated response to the prime feature and the need of correction due to a different task-relevant target feature (T. Schmidt, 2002; see also F. Schmidt et al., 2011; T. Schmidt, 2014; Vath & Schmidt, 2007; Vorberg et al., 2003).

This influence of the prime on target processing causes a measurable priming effect in response times and error rates. Hence, the characteristic ‘scissor-like’ pattern of motor responses emerges (see Fig. 8), representing the response time differences between inconsistent and consistent trials over prime-target SOA. This pattern is also observable in error rates. The typical time course of priming effects demonstrates a correlation between SOA and consistency. Hence, the greater the time interval between prime and target is (increasing prime-target SOA), the more power the prime has to trigger the consistent or inconsistent response (F. Schmidt et al., 2011; see also T. Schmidt, 2002).

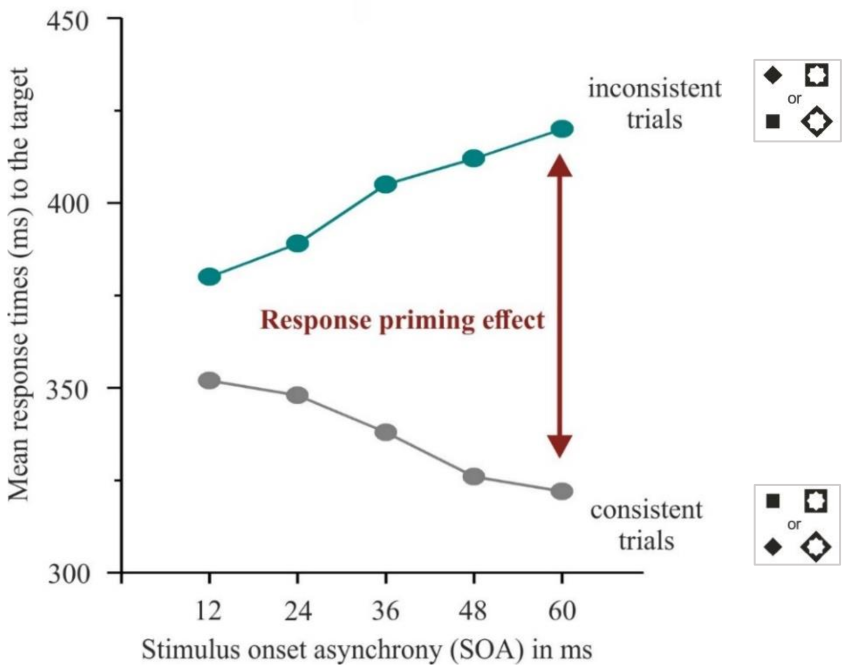


Figure 8. Fictitious data pattern for typical response priming effects over SOA. Primes are black squares or diamonds. Targets, which serve as metacontrast masks are black squares or diamonds with a central cut-out, able to mask both types of prime shapes. Priming effects are calculated by the response time differences of inconsistent and consistent trials. Consistent prime-target sequences result in faster reaction times, increasing over SOA (up to 100 ms). In contrast, inconsistent primes lead to a response conflict, causing slower responses. Interestingly, priming effects can increase with increasing SOA, no matter whether the prime is clearly visible (no masking) or (partially) invisible by techniques of visual masking. Adapted from F. Schmidt et al., 2011, p.121.

Fascinatingly, response priming can take place independently of visual awareness. This independence can be demonstrated by combining response priming with techniques of visual masking, which are usually used to reduce the visibility of a visual stimulus (F. Schmidt et al., 2011). Several studies clearly demonstrated that even if the prime was reduced in its visibility by masking, priming effects remained unaffected (e.g., Albrecht et al., 2010; Klotz & Wolff, 1995; Mattler, 2003; T. Schmidt, 2000, 2002; Vorberg et al., 2003). Under conditions of metacontrast backward masking, where the target itself serves as mask, priming effects can increase while the visibility of the prime decreases (i.e., visual awareness).

1.4 Double dissociations

A double dissociation is demonstrated if two variables run in opposite directions, indicating that both measures cannot rely on the same source of information (T. Schmidt & Vorberg, 2006; see also F. Schmidt et al., 2011). Hence, a double-dissociated data pattern between increasing priming effects and decreasing prime visibility (i.e., masking) most clearly indicates that different types of cognitive processes are underlying prime processing and prime awareness. In accordance with the classic dissociation paradigm, such a double dissociation needs to demonstrate that an indirect measure of response priming effects increases over time, reflecting the degree to which the prime stimulus affects behavior, while a direct measure of prime visibility decreases, depicting the degree to which the prime reaches visual awareness.

Example of a double dissociation:

a) **Indirect** measure b) **Direct** measure

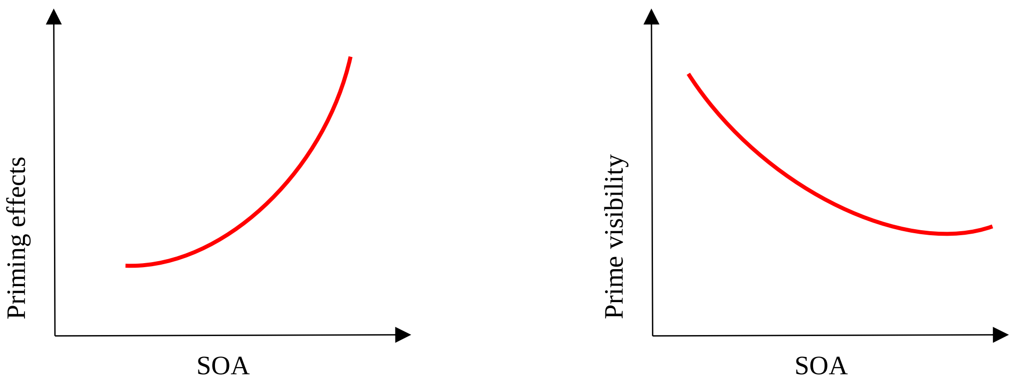


Figure 9 a) An indirect measure of priming effects, increasing over stimulus onset asynchrony. In indirect response priming tasks, speeded responses are usually made to the target stimulus which follows the prime, measuring the degree of prime influence on target processing (i.e., response priming effect, T. Schmidt & Vorberg, 2006; see also F. Schmidt et al., 2011) **b)** A direct measure of prime visibility (i.e., masking effect), forming a declining or u-shaped function over SOA. Most common for response priming studies with a direct measure of stimulus awareness are tasks with a direct report on prime visibility by using objective and/or subjective methods. Hence, participants can perform tasks where they are asked to discriminate, identify, or detect the prime, or where they are instructed to rate their confidence on the perceived brightness or clearness of the prime (F. Schmidt et al., 2011).

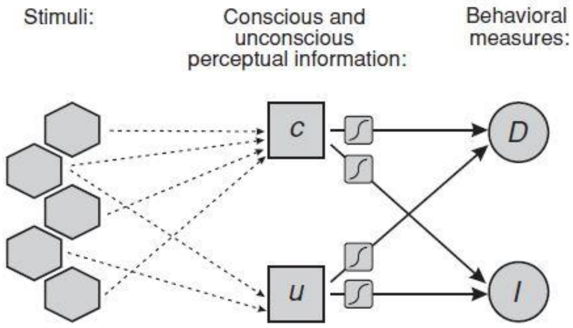
Based on this fascinating fact that priming effects and prime visibility can show opposite time courses, clearly demonstrating that stimulus processing can occur without stimulus awareness, double dissociations provide strong evidence that perception can occur without awareness. Nevertheless, the traditional way to demonstrate unconscious cognition has been to show a simple dissociation between a direct measure (*D*) of stimulus visibility at chance level (indicating that awareness to this stimulus is absent) and an indirect measure (*I*) showing an effect in behavior (Reingold & Merikle, 1988; see also T. Schmidt & Vorberg, 2006). In 2006, Thomas Schmidt and Dirk Vorberg demonstrated that this traditional zero-awareness criterion of simple dissociations involves statistical problems and methodological difficulties that can be avoided. For this reason, I will refer to the mathematical concept of T. Schmidt and Vorberg (2006)[22] where they provide criteria for three types of dissociations (simple-, double-, and sensitivity dissociations), showing that double dissociations require milder measurements assumptions than simple dissociations do. Judging from this perspective, double dissociations are more powerful since they circumvent all methodological restrictions of simple dissociations.

As noted, even though simple-dissociated patterns are intuitively convincing, they are equally problematic since they include some major issues regarding the measurement process. If perception without awareness is demonstrated by a simple dissociation, an indirect measure needs to show increasing effects over time, indicating that some critical information of the stimulus has been processed (e.g., prime color) while the direct measure of awareness (e.g., color discrimination performance) has to show chance performance. Actually, this zero-awareness criterion involves the problem of confirming a null hypothesis, assuming that unconscious processing does not exist ($u = 0$). Under this condition of the null model, it is assumed that only conscious information as the only information source accounts for the behavioral measures (e.g., direct and indirect), representing all relevant stimulus information. Important to note, the null model contrasts with alternative models, which assume that more than one variable is necessary to represent the perceptual information of a stimulus. In order to distinguish both models from each other, the authors developed a general model with exactly two variables, and labeled them *c* for conscious information, and *u* for unconscious information. Under the

[22] In contrast to the APA citation style, the source is mostly omitted in the following sections for better readability. Subsequently, the named authors and the publication year are for reference, and direct quotes only include the page number(s).

general model, the direct as well as indirect measure can be influenced by either type of input, and are defined as a function of these variables, $D = D(c,u)$, and $I = I(c,u)$. “The null model is identical to the general model, except for assuming that $u = 0$ throughout, or in other words that unconscious information does not exist …” (p. 491). As a consequence, “proponents of unconscious processing have to refute what we call *the null model of unconscious cognition*” (p. 490).

a) Assumptions under the **general model**



b) Assumptions under the **null model of unconscious cognition**

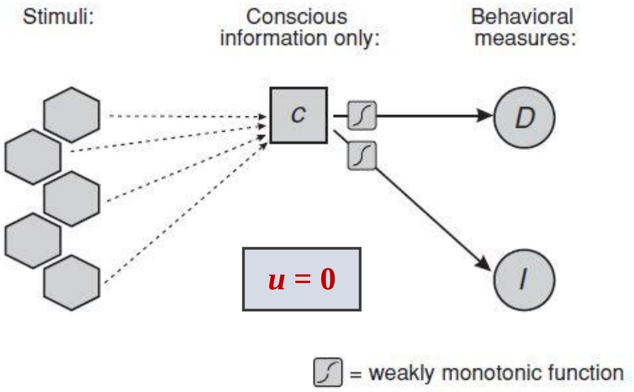


Figure 10 a) Assumptions of the general model. Direct (*D*) and indirect measures (*I*) are weakly monotonic functions of conscious (*c*) and unconscious (*u*) information. **b)** The null model of unconscious cognition is based on the same assumptions as the general model, except that *u* is not allowed. Since “a sensitive measure … should be able to reflect changes in the type of information it is intended to measure”, it “should not decrease when one of its arguments increases; rather, it should either increase or (at worst) remain constant” (p. 491). The authors refer to this as *weak monotonocity*, whereas a measure that obeys *strong monotonocity* has to show an increase whenever an argument increases. Adapted illustration of T. Schmidt and Vorberg (2006, p. 492).

However, for simple dissociation patterns with "values of *D* at chance level in the presence of nonzero *I"* (p. 491), some additional assumption must be made for a conclusive demonstration of unconscious perception. "In particular, *D* must be an exhaustive measure of conscious information" (p. 491). If not, *D* could reflect only some aspects of conscious information (and not all aspects), and the absence of a direct effect would not imply the absence of awareness. Thus, there could be some undetected conscious information that could cause an indirect effect above chance level. This is called the *exhaustiveness assumption* of simple dissociations (T. Schmidt & Vorberg, 2006; originally stated by Reingold & Merikle, 1988), where "*D* must be strongly monotonic with respect to *c*" (p. 492), and consequently has to be a noise-free measure[23]. Nevertheless, the refutation of the null model is not the only way to provide evidence of unconscious processing. An alternative way for simple dissociations to demonstrate unconscious processing is proposed by the authors with the *exclusiveness assumption.* More precisely, it is assumed that the "indirect measure *I* is exclusive for unconscious information [(*u*)]" (p. 492). Consequently, a change in *I* would imply unconscious processing, independent of the value of *D.* However, the meaningfulness of the dissociation procedure would be lost, whenever the value of one measure is negligible anyway.

An empirical finding that contradicts the null model and all the restrictions of a simple dissociation is a double-dissociated pattern, showing that the same manipulation leads to opposite effects in *D* and *I* [24]. Then, *D* and *I* must be driven by at least two types of information, responding differently to some kind of manipulation (see Fig. 11).

[23] No empirical measure is precise enough to meet this assumption (T. Schmidt & Vorberg, 2006).

[24] Under the assumptions of the null model, a change in *c* should consequently lead to a change in *D* and *I* in the same direction, or it should leave both unchanged. A change of *D* and *I* in opposite directions, as expected under the assumptions of a double dissociation, is not possible under the null model (T. Schmidt & Vorberg, 2006).

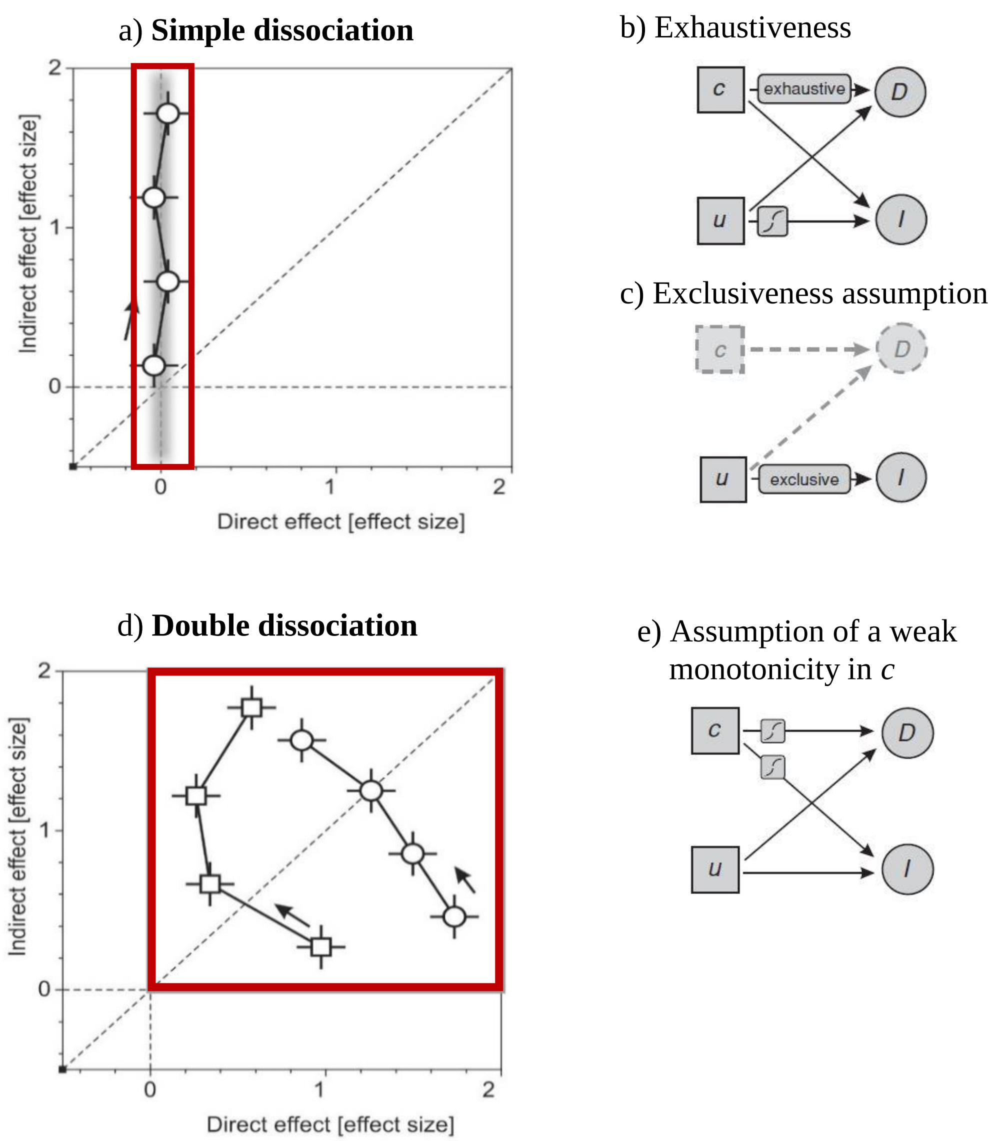


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Figure 11 a) Data pattern of a simple dissociation, consisting of nonzero indirect effects (*I*) when direct effects (*D*) are at chance level. Data patterns are only valid when statistically close to the $D = 0$ line. **b)** Simple dissociations require the assumptions that *D* is exhaustive for conscious information and that *I* is a weakly monotonic function of unconscious information. **c)** Alternatively, *I* can be an exclusive measure of unconscious information *u*. **d)** Two examples of double dissociations. Circles: indirect effects are increasing while direct effects are decreasing over the range of an independent variable. Squares: indirect effects are increasing while direct effects form a u-shaped visibility function. Arrows mark the ordering of the levels of an independent variable from smallest to largest. Data patterns are valid in the entire *D*-*I* space. **e)** Double dissociations only require the assumption that *D* and *I* are weakly monotonic functions of conscious information. Adapted illustration from Biafora and Schmidt (2020, p. 3; see T. Schmidt & Vorberg, 2006 for a similar illustration).

Hence, double dissociations do not require the direct effect to be zero (zero-awareness assumption of simple dissociations), working under milder assumptions than the general model where only direct (*D*) and indirect (*I*) measures must be weakly monotonic in *c* (T. Schmidt & Vorberg, 2006).[25] A double dissociation places very few constraints on the possible interactions between conscious and unconscious information, showing that performance on one measure cannot explain the performance on the other. For this reason, supported by empirical findings (e.g., Mattler, 2003; Vorberg et al., 2003), a double dissociation between the processing of stimulus information and an observer's conscious perception of this information is one of the most powerful data patterns as it provides strong evidence that different cognitive processes are underlying these two processes (e.g., color processing and color awareness).

[25] The monotonicity assumption for functions of *u* can be abandoned (T. Schmidt & Vorberg, 2006).

2. Experiments Part I: Induced dissociations[26]

2.1 Introduction

There is no doubt that naturally occurring double dissociations are arguably the strongest type of dissociation that can be found in empirical data. However, a major drawback of double dissociations is that they are hard to find, since they only occur if two processes generate opposite effects. Hence, double dissociations are the exception rather than the rule while simple dissociations are still more popular and most commonly used to demonstrate perception without awareness (T. Schmidt & Vorberg, 2006).

Motivated by this fact, my supervisor Prof. Dr. Thomas Schmidt and I created a technique where double dissociations can be artificially induced. More precisely, the shape of the masking function can be altered into a desired direction, while the increasing time course of the priming function remains untouched by this technique. As a result, direct and indirect measures can demonstrate a double-dissociated data pattern.

Actually, double dissociations (as well as simple dissociations) have already been demonstrated in response priming experiments (e.g., Vorberg et al., 2003; Albrecht & Mattler, 2010; Mattler, 2003). However, in those studies dissociations appeared naturally and without controlled experimental manipulations due to the time course of masking functions. Although in practice it seems less difficult to generate increasing priming effects of an indirect measure; still, simultaneously generating a decreasing or u-shaped masking function is quite challenging. Since the time course and magnitude of masking is strongly observer-dependent, even though relatively consistent for each individual (Albrecht et al., 2010; Albrecht & Mattler, 2010, 2012, 2016), it is difficult to find stimulus parameters that can create a specific type of masking function for the majority of observers.

[26] The following experimental sections mainly correspond with my publication Biafora, M., & Schmidt, T. (2020). Induced dissociations: Opposite time courses of priming and masking induced by custom-made mask-contrast functions. *Attention, Perception, & Psychophysics*. https://doi.org/10.3758/s13414-019-01822-4. Some parts contain the exact wording and/or figures; other parts are adjusted to my present thesis. Reprinted by permission from Copyright Clearance Center, Springer Nature Customer Service Center: Springer Nature, Attention, Perception & Psychophysics, Induced dissociations: Opposite time courses of priming and masking induced by custom-made mask-contrast functions, Biafora, M., & Schmidt, T., License Number: 5166370374382, 2020.

Usually, in a simple metacontrast response priming experiment (e.g., two choice responses to a mask preceded by a prime), the prime-mask SOA is varied as a single, independent variable, and strongly masked primes are compared with weakly masked primes. Strong masks are equipped with maximum contrast, whereas weak masks use a luminance contrast at minimum. Under these conditions, mask contrast and SOA are viewed as independent factors, and each of these two masking conditions (strong mask vs. weak mask) yields a priming function, $P(s)$, and a masking function, $M(s)$, i.e., an indirect and direct measure as a function of SOA. Nonetheless, mask contrast can also be expressed as a function of SOA, where mask contrast and SOA are coupled. This procedure generates a so-called *mask-contrast function*, $MCF(s)$. Now, masking is controlled by altering the luminance contrast of the mask coupled with SOA. Accordingly, two mask-contrast functions with either maximum contrast (c_{max}) for strong masking or minimum contrast (c_{min}) for weak masking are generated, and both are constant across SOA, $MCF_{max}(s) = c_{max}$ and $MCF_{min}(s) = c_{min}$. Mask-contrast functions with a maximum contrast, $MCF_{max}(s)$, are expected to lead to masking functions near chance level, since they produce strong masking of the prime. Mask-contrast functions with a minimum contrast, $MCF_{min}(s)$, should consequently produce low masking effects. Under conditions where the masking function is convincingly close to zero while the priming function is larger than zero, a simple dissociation is induced, $M(s) \approx 0$, $P(s) > 0$.

For creating a double dissociation, two more MCFs need to be added: one where mask contrast decreases with SOA from c_{max} to c_{min}, $MCF_{dec}(s)$; and one where it increases from c_{min} to c_{max}, $MCF_{inc}(s)$. This manipulation should bend the masking functions into new shapes. Ideally, for an induced double dissociation, priming functions should continue to increase under both masking regimes, while increasing and decreasing MCFs should lead to masking functions with opposite effects, respectively. Hence, if mask contrast decreases with SOA, strong masking at the shortest SOA and weak masking at the longest SOA is expected. Conversely, if mask contrast increases with SOA, there should be relatively less masking at short SOAs and relatively more masking at long SOAs. The two masking functions resulting from increasing and decreasing MCFs should be bounded from above and below by the MCFs constant at c_{max} *and* c_{min}, respectively. Specifically, $MCF_{max}(s)$, $MCF_{min}(s)$, $MCF_{inc}(s)$, and $MCF_{dec}(s)$ denote the *mask-contrast functions* with maximum, minimum, increasing, or decreasing mask contrast; while $M_{max}(s)$, $M_{min}(s)$, $M_{inc}(s)$, and $M_{dec}(s)$ denote the resulting *masking functions*.

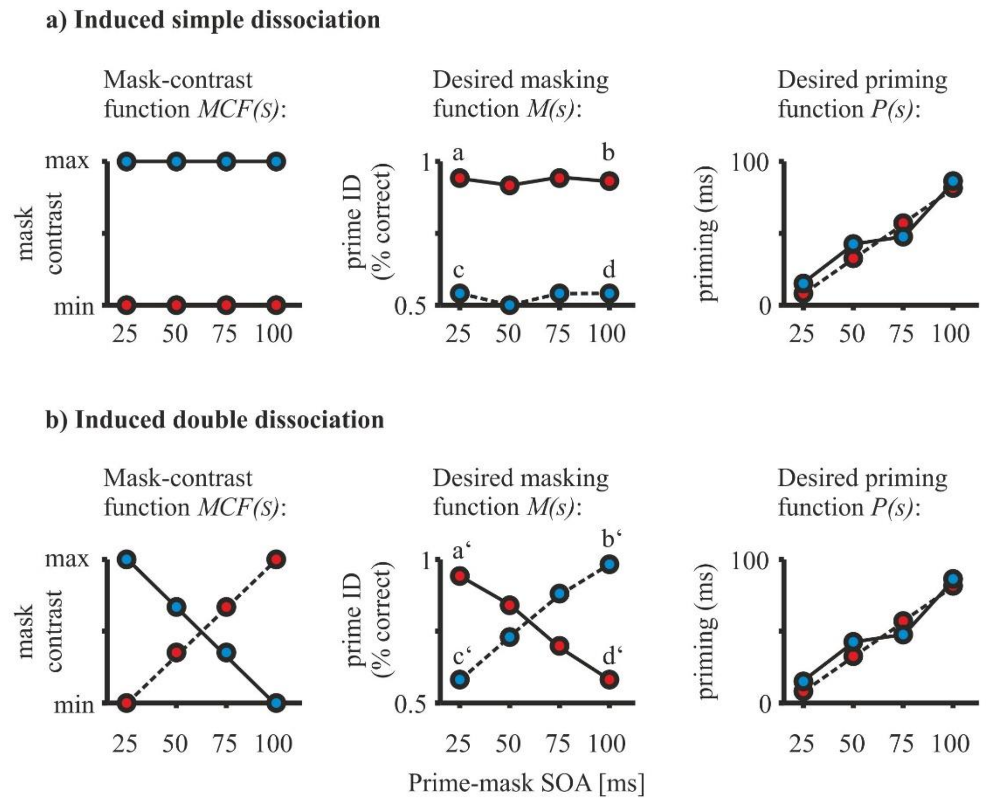

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Figure 12 a) Induced simple dissociation. Mask-contrast functions with maximum contrast should lead to masking functions near-chance level, whereas mask-contrast functions with minimum contrast should lead to a weak masking effect and masking functions at a high-performance level of prime discrimination. Ideally, priming functions should continue to increase over SOA, demonstrating that priming effects remain unaffected by masking. **b)** Induced double dissociation. Mask-contrast functions of decreasing mask contrast should lead to increasing performance in prime discrimination, whereas increasing mask-contrast functions are expected to lead to decreasing prime discrimination. Ideally, priming functions should continue to increase under both masking regimes. Note that within measurement error, data points marked a-a', b-b' etc. should correspond because they depend on physically identical stimulus conditions (*principle of connected endpoints*).

In general, there are three steps to create custom-made mask-contrast functions (MCFs) with this technique: (1) Two extreme luminance contrasts for the mask stimuli need to be chosen. The SOA is ordered from 1 to n. These maximum and minimum contrast stimuli form the endpoints of the future MCFs. (2) Mask stimuli within these endpoints need to be added to create a seamless transition from maximum to minimum contrast, and vice versa. Hence, mask-contrast functions should gradually increase from minimum to maximum contrast across SOAs, and gradually decrease from maximum to minimum contrast across SOAs. (3) Mask stimuli with maximum and minimum contrast can be added to link the endpoints of either maximum or minimum contrast. This step can also be omitted, since it is for validation purposes only.

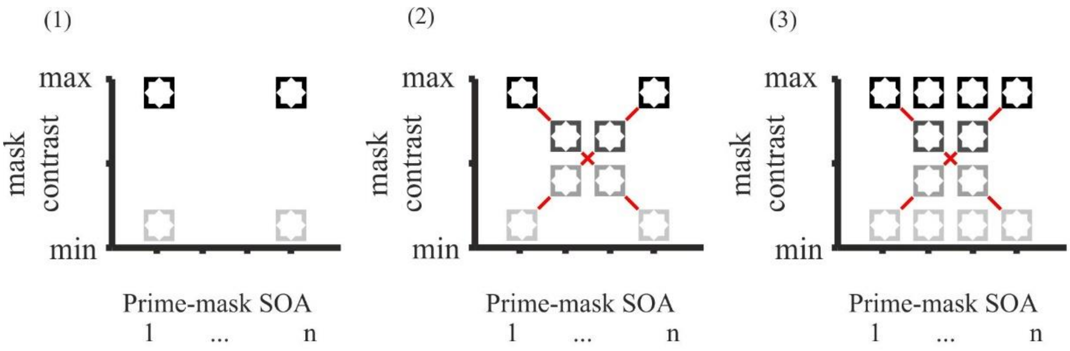

Figure 13. Step-by-step guide for custom-made mask-contrast functions (MCFs). (1) Two extreme mask contrasts form the endpoints of the MCFs. (2) Between these endpoints, mask stimuli gradually vary with SOA from maximum to minimum contrast, and vice versa. (3) Mask-contrast functions with maximum or minimum contrast constant across SOA can be added for validation purposes.

The following three experiments[27] were designed to explore the possibilities of response priming under custom-made mask-contrast functions. More detailed, applying this technique of induced dissociations, different mask contrasts as a function of prime-mask SOA were compared in terms of their property to induce a double dissociation between priming and masking functions.

2.2 Experiment 1: MCFs with masks of shape

In Experiment 1, simple geometrical shapes (squares and diamonds) were used as primes and masks. The mask's inner contours were designed to mask the prime by metacontrast, and prime-mask SOA was systematically coupled with the contrast of the entire mask. This procedure resulted in four mask-contrast functions (MCFs) with

[27] The experiments are reported in chronological order.

increasing, decreasing, low and high luminance contrast.[28] To assess the impact of these four MCFs on priming and masking functions, participants performed two tasks with the exact same stimuli and procedure. They either had to discriminate the mask shape under time pressure (mask identification task as an indirect measure of priming effects), or to discriminate the prime shape without time pressure (prime identification task as a direct measure of masking effects, i.e., prime visibility). The crucial question was whether the different mask-contrast functions would affect the masking functions while leaving the time course of priming intact. For establishing an induced double dissociation, priming effects should increase with SOA even under conditions of increasing masking effects (i.e., decreasing prime discrimination).

2.2.1 Methods

Participants. Six students from the Technische Universität Kaiserslautern (TUK, 3 men; 5 right-handed; age range 22-33 years) took part in eight one-hour sessions. Their vision was normal or corrected to normal. All participants were naïve to the purpose of the study and received either course credit or 7 € per hour of participation. Each of them gave informed consent and was treated according to the ethical guidelines of the American Psychological Association (APA). After the final session, they were debriefed and received an explanation of the experiment.

Apparatus. Participants were seated in a dimly lit room in front of a color cathode-ray monitor (1280x1024 pixels, retrace rate 75 Hz) at a viewing distance of approximately 60 cm.

Stimuli and Procedure. We used stimuli similar to those by Mattler (2003). All stimuli appeared against a white background of 48.2 cd/m². Primes were black squares or diamonds (0.04 cd/m²) with an edge length of 1 cm (0.96° of visual angle) that appeared at fixation (about foveal metacontrast, see Ventura, 1980). Masks were squares or diamonds with an edge length of about 1.6 cm (1.53°) appearing at the same position as the primes. Masks had a central cut-out corresponding to the superposition of a square and a diamond prime, so that prime and mask shared adjacent contours and both prime shapes would be

[28] MCFs with low and high contrast were employed for purposes of validation and for comparison with earlier data.

masked by metacontrast (Breitmeyer & Öğmen, 2006). The fixation point was presented in black at the center of the screen.

There were two session types. In Session Type 1, masks were either of high contrast to the white background (high MCF, 0.04 cd/m²) or of low contrast (low MCF, 43.47 cd/m²) at all SOAs. In Session Type 2, four different levels of luminance were used (0.04, 3.65, 16.97, or 43.47 cd/m²) such that mask contrast either increased or decreased with SOA (increasing and decreasing MCF, respectively). The experiment consisted of a mask and a prime identification task performed in different sessions, each session comprising 31 blocks with 32 trials. The first block was always a practice block. Each trial started with a central fixation point, followed by a prime presented for 27 ms that was either the same shape as the mask (consistent trial) or the other shape (inconsistent trial). Finally, the mask appeared after a prime-mask SOA of 27, 40, 53, or 67 ms, and remained on screen until response. Time from fixation to mask onset was constant at 600 ms.

Participants were instructed to keep their gaze on the fixation point and press the ‘F’ button upon seeing a diamond, or the ‘J’ button upon seeing a square, using the index fingers. This assignment was counterbalanced across participants. In the mask identification task (*mask ID* or *mID*), they were asked to respond to the shape of the mask as quickly and correctly as possible. They received visual feedback if the response was incorrect or too slow (response time [RT] > 1000 ms). In the prime identification task (*prime ID* or *pID*), participants responded to the shape of the prime without time pressure and without trial-to-trial feedback. After each block, participants received summary feedback (in the mask ID, on mean reaction time, mean accuracy, and number of errors; in the prime ID, on mean accuracy only). Participants could take a break after each block.

Each participant took part in eight sessions. Each session contained either low and high MCFs (Type 1) or increasing and decreasing MCFs (Type 2), resulting in two sessions of the mask ID (Type 1), followed by two sessions of prime ID (Type 1), mask ID (Type 2), and prime ID (Type 2). Sessions were usually carried out on different days, rarely in two sessions per day (with a break of at least two hours). All combinations of prime shape, prime-mask consistency, and SOA were presented equiprobably and pseudo-randomly in each block.

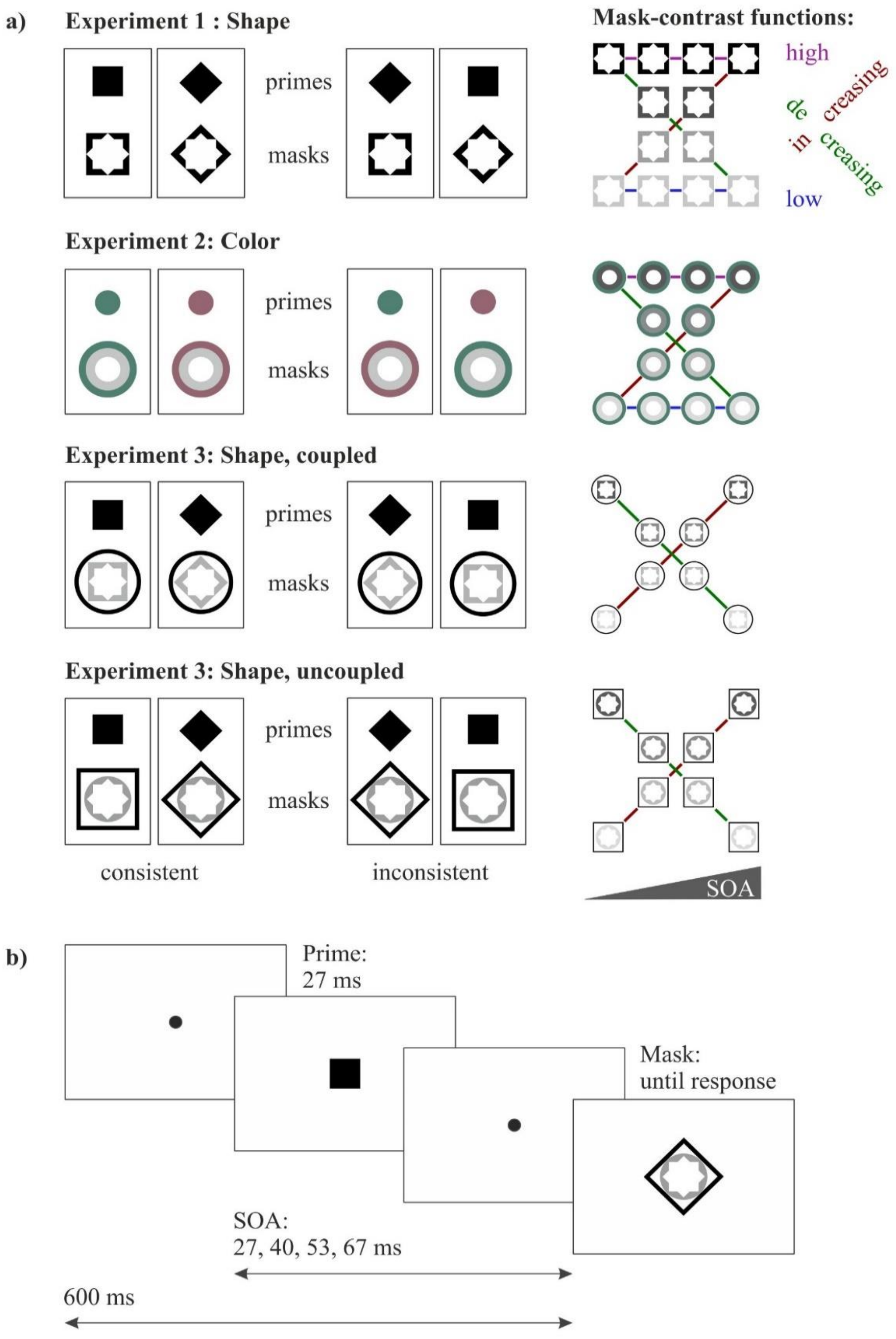

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Figure 14 a) Prime stimuli, mask stimuli, and mask-contrast functions (MCFs) employed in all three experiments. Mask-contrast functions are color-coded: *blue* – low MCF, *purple* – high MCF, *red* – increasing MCF, *green* – decreasing MCF. **b)** Time course of a trial, illustrated for an inconsistent trial in Experiment 3.

Data treatment and statistical methods. Dependent variables were response time and error rate in the mask identification task, and response accuracy in the prime identification task. Practice blocks were not analyzed. Reaction times were summarized by trimmed means; error trials were excluded from response time analysis. In the mask identification task, response times shorter than 100 ms or longer than 999 ms were eliminated as outliers (0.16 % in Session Type 1, 0.11 % in Session Type 2). Repeated-measures analysis of variance (ANOVA) was performed with factors of mask-contrast function (*MCF*), prime-mask SOA (*S*), and prime-mask consistency (*C*, in analyses of priming effects only). Error rate and response accuracy were arcsine-transformed to meet ANOVA requirements (Winer et al., 1991). For clarity, all results are reported with Huynh-Feldt-corrected *p* values and the original degrees of freedom, and effects are specified by subscripts to the *F*-values (e.g., F_{CxS} for the interaction of consistency and SOA). All ANOVA effects significant at $p \leq .05$ were reported, so that unreported effects are always nonsignificant, with the understanding that *p* values between .01 and .05 should be regarded with caution (*p* values between .05 and .10 were mentioned if important to the argument).

In multifactor repeated-measures designs, statistical power is difficult to predict because too many terms are unknown. Instead, measurement precision is controlled at the level of individual participants in single conditions. Precision is calculated as $s/\sqrt{r}$ (Eisenhart, 1963), where *s* is a single participant's standard deviation in a given cell of the 2x4-design (2 consistencies: consistent, inconsistent; 4 SOAs: 27 ms, 40 ms, 53 ms, 67 ms) and *r* is the number of repeated measures per cell and subject. With *r* =120 and 240 in the mask identification and prime identification task, respectively, a precision of about 5.5 ms in response times (assuming individual SDs around 60 ms), at most 4.6 percentage points in error rates, and at most 3.2 percentage points in prime identification accuracy (assuming the theoretical maximum SD of .5) was expected. Precision thus exceeds our previous recommendations for response priming studies (*r* = 60, F. Schmidt et al., 2011; Smith & Little, 2018).

2.2.2 Results and Conclusion

Since the level of prime identification performance over time reflects the amount of masking effect on the prime, it will be referred to it as masking function. Response times received by the mask identification task are used to calculate the response priming effect. This response priming effect over prime-mask SOAs is represented by the priming function. Moreover, since the time course and magnitude of masking is strongly observer dependent (type-A vs. type-B observer, Albrecht et al., 2010; Albrecht & Mattler, 2010, 2012, 2016), data was analyzed at the level of single individual observers.

Masking effects

Session Type 1: Prime ID under low versus high mask contrast. Under conditions of low mask contrast, it was expected that prime discrimination performance would be high, whereas prime ID performance should be low under high mask contrast.

Averaged across observers, performance under high-contrast masking was lower than under low-contrast masking, and performance slightly increased with SOA (Fig. 15). Repeated-measures ANOVA of SOA (S) and mask-contrast function (MCF) only revealed a main effect of mask-contrast function, F_{MCF} (1, 5) = 6.47, p = .052, and SOA, F_S (3, 15) = 4.14, p = .042, but no interaction.[29] Simple tests indicated that the SOA effect was not significant in either masking function.

Session Type 2: Prime ID under increasing versus decreasing mask contrast. According to the predictions of induced dissociations (Fig. 12), it was expected that prime ID performance should increase for decreasing mask contrast, while under conditions of increasing mask contrast a decreasing masking function should be generated.

Performance under decreasing mask contrast was low at the shortest SOA and then increased with SOA. As intended, performance under increasing mask contrast started much higher for the shortest SOA but ended lower at the longest SOA, so that the functions crossed at the 53-ms SOA. Overall, the masking function was v-shaped (Fig. 15, left panel). Averaged across observers, ANOVA only suggested a main effect of SOA, F_S (3, 15) = 3.70, p = .036, and a significant interaction, F_{MCFxS} (3, 15) = 5.95, p = .029. Simple tests showed a significant SOA effect for decreasing MCF, p = .008, but not for

[29] Note that the lackluster p values are not due to low measurement precision but large differences between individuals (see Figure 17).

increasing MCF. Note that the principle of connected endpoints is violated here: Performance in physically identical stimulus conditions was better by about 10 percentage points in Session Type 2 than in Session Type 1, $t(5) = -2.76$, $p = .040$, suggesting that the blocking of masking functions into separate sessions had a systematic impact on performance.

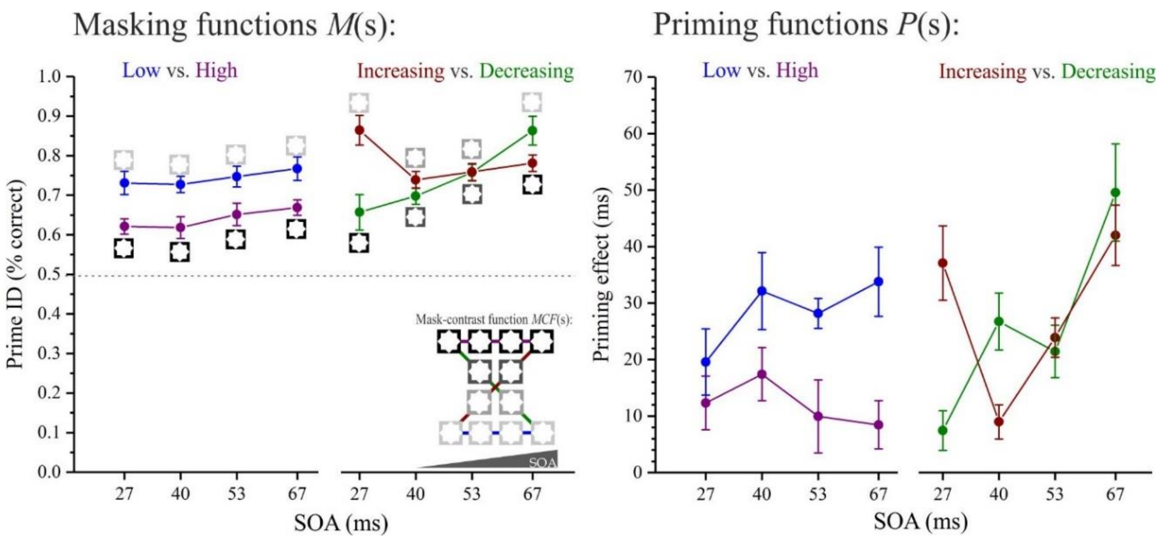

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Figure 15. Experiment 1. *Left panel:* Results of the prime ID for both session types (*left*: Session Type 1; *right*: Session Type 2). *Right panel*: Priming effects ($RT_{incon} - RT_{con}$) for both session types. Standard errors of the mean are calculated across subjects and corrected for intersubject variance (Cousineau, 2005). Inlays illustrate the respective masking conditions. Only square targets are shown.

Priming effects

Based on previous work, clear predictions for priming under three of four MCFs can be made. For the high and low MCFs, priming effects should increase with SOA. Because response priming effects increase with prime contrast and decrease with target contrast (F. Schmidt et al., 2011; T. Schmidt & Schmidt, 2018), priming effects should be larger for low-contrast than for high-contrast masks. For the same reason, priming effects should strongly increase with SOA under conditions of decreasing mask contrast. For the conditions of increasing mask contrast, a monotonically increasing priming effect should be found that would be in opposition to the decreasing masking function. Priming effects in error rates should follow the same general pattern as priming effects in response times.

For each session type, a repeated-measures ANOVA with factors of consistency (*C*), SOA (*S*), and mask-contrast function (*MCF*) was performed.

Session Type 1: Mask ID under low versus high mask contrast. Responses were faster for consistent than for inconsistent trials, F_C (1, 5) = 52.02, p = .001 (Fig. 16). This response priming effect (Fig. 15, right panel) was larger for weak than for strong masks, F_{CxMCF} (1, 5) = 30.66, p = .003. Responses were also slower for weak than for strong masks, F_{MCF} (1, 5) = 55.14, p = .001, a difference diminishing with SOA, F_{MCFxS} (3, 15) = 3.56, p = .040. All other effects were nonsignificant. An analogous analysis of the error rates revealed no significant priming effects. Overall, more errors occurred for weak than for strong masks, F_{MCF} (1, 5) = 7.17, p = .044. There was a somewhat puzzling interaction of mask type and consistency indicating that priming effects were of positive sign for weak masks but were reversed for strong masks, F_{CxMCF} (1, 5) = 16.81, p = .009. However, simple tests performed separately for the two mask types revealed no significant effects in either masking condition.

Session Type 2: Mask ID under increasing versus decreasing mask contrast. Overall, response times formed a u-shaped function of SOA, F_S (3, 15) = 30.43, p < .001 (Fig. 16). Responses were faster for consistent than for inconsistent trials, F_C (1, 5) = 88.19, p < .001, and this priming effect (Fig. 15, right panel) increased with SOA, F_{CxS} (3, 15) = 17.75, p < .001. Response times increased with SOA under conditions of decreasing mask contrast, but decreased with SOA under increasing mask contrast, F_{MCFxS} (3, 15) = 38.82, p = .001. All other effects were nonsignificant apart from a significant triple interaction, $F_{MCFxCxS}$ (3, 15) = 30.89, p < .001, showing different time-courses of the priming effect in the two masking conditions. Roughly, under decreasing mask contrast, priming effects were small at the shortest SOA and then grew larger. Under increasing mask contrast, however, priming effects were large at the shortest SOA, broke down at the next-largest SOA, and only then continued to increase. Note that the smallest priming effect occurred at the same SOA (40 ms) where prime identification accuracy was also lowest, so that no double dissociation was established.

An analogous ANOVA of the error rates showed that more errors occurred in inconsistent than consistent trials, F_C (1, 5) = 15.39, p = .011, and that error rates varied with SOA, F_S (3, 15) = 12.73, p < .001. Priming effects were larger at the shortest and longest SOA than at intermediate SOAs, F_{CxS} (3, 15) = 4.30, p = .024, mainly due to the conditions with increasing mask contrast.

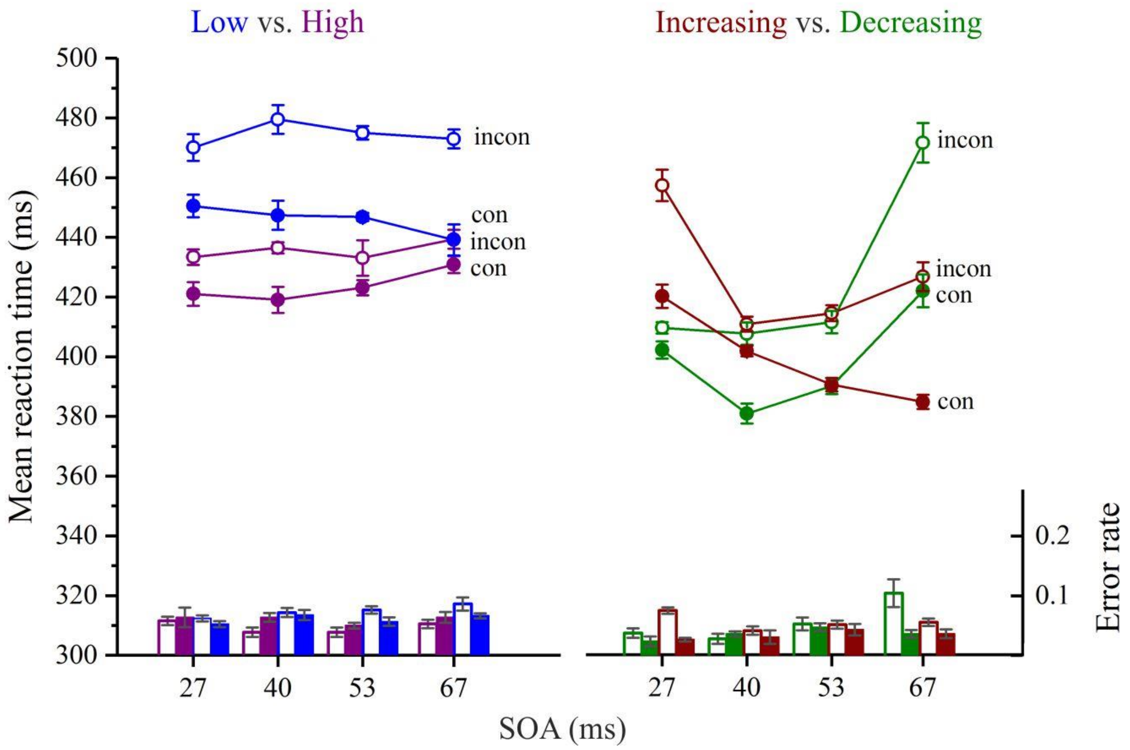

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Figure 16. Experiment 1. Mean reaction times and error rates for all mask-contrast functions, separately for both session types (*left*: Session Type 1; *right*: Session Type 2) and for consistent (con) and inconsistent (incon) trials. Standard errors of the mean are calculated across subjects and corrected for intersubject variance.

Individual differences in masking and priming

Previous research has shown that participants can differ strongly in their time course of visual masking (type-A or type-B observer). Therefore, group data should be interpreted with caution and averaging data across type-A and type-B observers is not always advisable (Albrecht & Mattler, 2010). Indeed, participants differed greatly in the degree as well as the time course of masking (Fig. 17). Four out of six observers responded to the manipulation of mask contrast. Of the two observers who failed to do so, one performed almost perfectly throughout all masking conditions (ceiling effect, Participant 5) and one was at chance throughout all conditions (floor effect, Participant 6). In contrast, participants were quite homogenous regarding the pattern of response priming effects, despite marked differences in overall response speed. However, it is noteworthy that there is no indication of a double dissociation between priming and masking even at the individual level. First, under low or high MCFs, none of our participants shows type-B masking. Second, participants tend to show larger priming effects in precisely those conditions where they also perform better at prime discrimination. Third, under increasing mask contrast, all six observers show a dip in priming effects at the second-shortest SOA, which is exactly the condition where prime discrimination is most impaired.

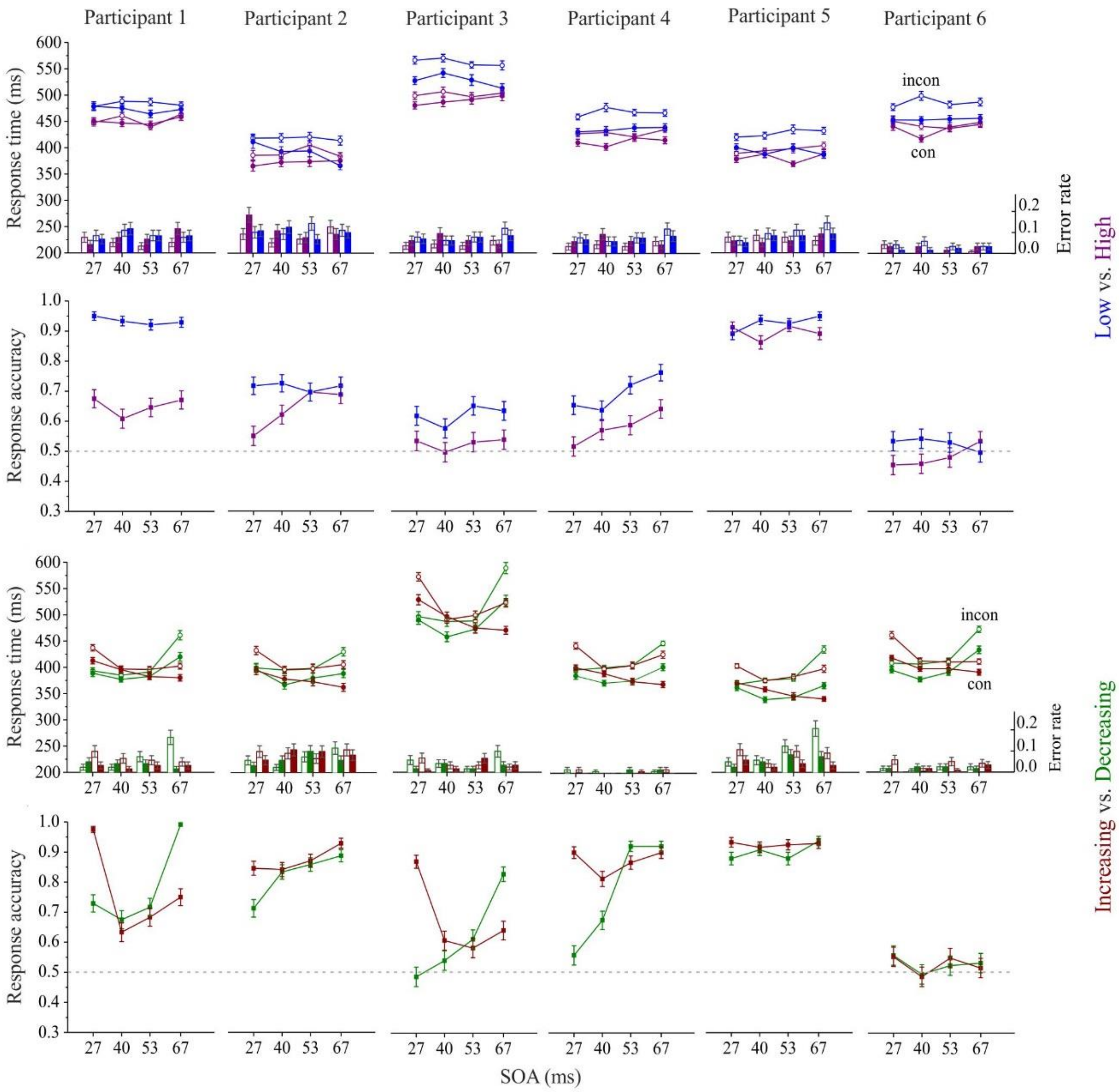

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Figure 17. Results for each individual participant in Experiment 1. Standard errors of the mean are calculated across trials.

Conclusion

Experiment 1 is no success for the new method. Nevertheless, the level and time course of prime discrimination performance was strongly influenced in the majority of observers by controlling mask contrast as function of SOA. This manipulation is successful in inducing decreasing or u-shaped masking functions in some observers who would otherwise show only type-A masking. Also, response priming effects were homogenous across observers despite large differences in masking functions: Priming effects are basically the same no matter whether prime discrimination is at chance (Participant 6) or nearly perfect (Participant 5), and no matter whether masking functions do or do not cross (Participants 1 & 3 vs. 2 & 4). However, the double dissociation that should be generated did not occur, neither at the group nor at the individual level: In the crucial condition of increasing mask contrast, priming effects decrease in exactly those conditions where prime discrimination performance is also lowest. So, even though there is plenty of evidence in this data set that the ability to identify the prime is no predictor of the priming effect, no double dissociation between priming and masking was induced.

Why the failure? There are indications that Experiment 1 confounded two aspects of the mask: its ability to reduce prime visibility (masking aspect) and its ability to activate the response (priming aspect). Generally, priming effects decrease with increasing target contrast because stronger targets are more effective in counteracting response activation from the prime (Haberkamp et al., 2013; F. Schmidt et al., 2011; T. Schmidt & Schmidt, 2018). In line with this, a relative reduction in priming is observed in those conditions where the mask has high contrast (because mask and target are the same stimulus). Therefore, it is suspected that Experiment 1 failed to produce a double dissociation because the backward-masking aspect of the imperative stimulus was coupled to its response-activation aspect. In Experiment 2, those features were decoupled, allowing them to act independently on the masking and priming functions.

2.3 Experiment 2: MCFs with masks of color

Experiment 2 switched to a domain where double dissociations between masking and response activation have not been observed before: response priming by color under metacontrast masking. If a colored prime is followed by a metacontrast mask of a different color, strong masking can occur provided that the colors are sufficiently desaturated. Previous research has shown strong response priming when the prime's color cannot be discriminated (Breitmeyer et al., 2004, 2007; T. Schmidt, 2000, 2002). However, only type-A masking is typically observed under metacontrast by heterochromatic color stimuli (Breitmeyer & Öğmen, 2006), and therefore no double dissociation has ever been reported for response priming by color.

In Experiment 1, the mask’s ability to active a response was confounded with its ability to mask the prime. For this reason, in Experiment 2 those properties were decoupled by separating the mask into two parts. Participants responded to the color (red or green) of a ring-shaped mask preceded by a disk-shaped prime either consistent or inconsistent in color. Only the outer part of the mask was colored and thus able to activate the response, while the inner part was presented in grayscale and designed to mask the prime by metacontrast (Fig. 14). Only the luminance contrast of the inner part was manipulated to control the degree of masking, independent from response activation from the colored outer part. As before, increasing and decreasing mask-contrast functions were compared, but once again low and high MCFs were included to validate the principle of connected endpoints in an improved design where all masking conditions were randomly intermixed instead of blocked. With this setup, priming effects in response times and error rates should increase with SOA under all MCFs, irrespective of the time course of masking.

2.3.1 Methods

Participants. Six students from the TUK (3 male; 5 right-handed; mean age 26.3 years) took part in eight one-hour sessions. Their vision was normal or corrected to normal. All but two participants were naïve to the purpose of the study and received 7 € per hour of participation. Each of them gave informed consent and was treated according to the ethical guidelines of the APA. After the final session, they were debriefed and received an explanation of the experiment.

Apparatus, stimuli, and procedure. The apparatus and procedure were identical to Experiment 1 except for new stimuli. Prime stimuli were red or green disks (diameter of 0.86°) which exactly fitted the inner cutout of the masks. Mask stimuli were annuli, consisting of a colored outer ring (outer diameter 1.92°) and a gray inner ring (outer diameter 1.54°, inner diameter the size of the prime) with a luminance of either 4.69, 12.6, 25.03, or 23.47 cd/m². Red and green stimuli were desaturated in color to allow for metacontrast masking (T. Schmidt, 2000) and had CIE coordinates of x = 0.33 and 0.25,

$y = 0.26$ and 0.31, respectively. They were similar in luminance (red: 5.28 cd/m²; green: 7.70 cd/m²). The mask and prime ID were performed in alternating sessions, each session comprising 31 blocks with 32 trials. Participants were instructed to keep their gaze on the fixation point and press the ‘F’ button for red stimuli or the ‘J’ button for green stimuli, using the index fingers. This assignment was counterbalanced across participants. In mask ID, they were asked to respond to the color of the mask (i.e., its outer ring) as quickly and correctly as possible. In the prime identification task, they responded to the color of the prime without time pressure. Feedback was given as in Experiment 1.

Data treatment and statistical methods. Trimming of response times and data analysis proceeded as in Experiment 1 and eliminated 0.07 % of trials in mask ID. Because the trial structure is identical to Experiment 1, a measurement precision of 5.5 ms in response times, at most 4.6 percentage points in error rates, and at most 3.2 percentage points in prime identification accuracy is expected.

2.3.2 Results and Conclusion

Masking effects

As in Experiment 1, prime discrimination performance should be high under low mask contrast, low under high mask contrast, and increasing for decreasing mask contrast. Under conditions of increasing mask contrast, a decreasing or u-shaped masking function should be generated.

Prime ID under low versus high mask contrast. As expected, prime discrimination performance was better under low rather than under high mask contrast, F_{MCF} (1, 5) = 15.99, p = .010 (Fig. 18 left panel). Mask function interacted with SOA, such that performance increased with SOA at high mask contrast but decreased at low mask contrast, F_{MCFxS} (3, 15) = 12.87, p = .005. Simple tests showed that both the increase and the surprising decrease were significant, p = .002 and .027. There was no significant main effect of SOA.

Prime ID under increasing versus decreasing mask contrast. Performance increased with SOA under decreasing mask contrast (Fig. 18, left panel). Under increasing mask contrast, performance strongly decreased between the shortest two SOAs and then remained constant. The different time-courses led to a significant interaction of mask function and SOA, F_{MCFxS} (3, 15) = 10.93, p = .017. Overall, performance was better under increasing mask contrast, F_{MCF} (1, 5) = 12.99, p = .015, and increased with SOA, F_S (3, 15) = 5.46, p = .010. Simple tests showed significant SOA effects for both decreasing and increasing MCFs, p = .020 and .010, respectively. Note that the principle of connected endpoints is well met, so that performance levels are similar in physically identical conditions, $t(15) = -1.63$, p = .164.

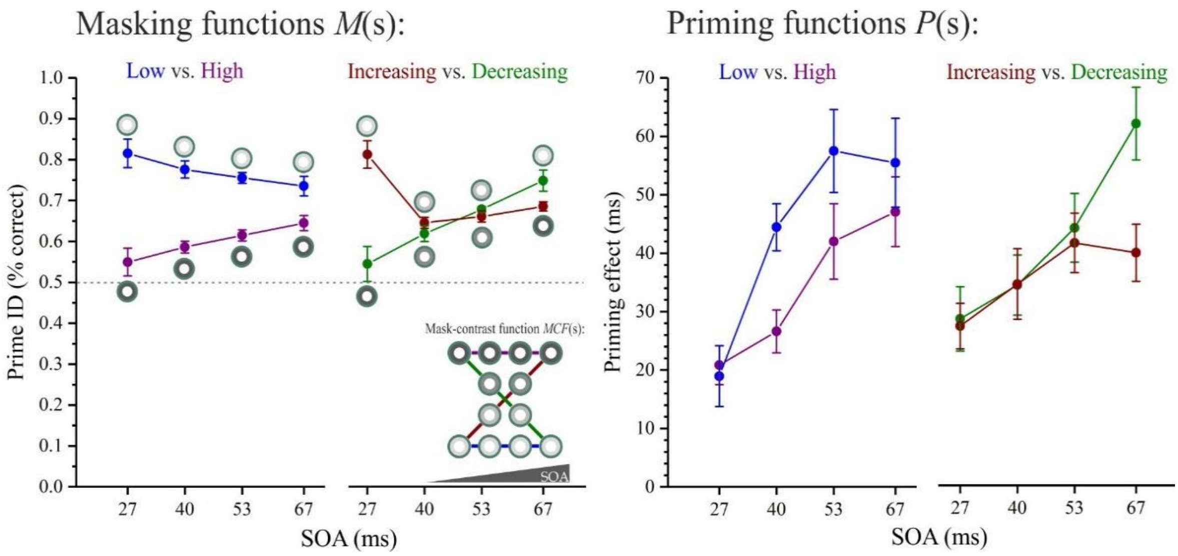

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Figure 18. Experiment 2. *Left panel*: Results of the prime ID for all masking functions. Overall response accuracy is averaged across consistency. *Right panel*: Priming effects for all masking functions. Inlays illustrate the respective masking condition. Only green masks are shown.

Priming effects

It was expected that priming effects would increase with increasing SOA for all mask-contrast functions because the mask's ability to activate responses was now decoupled from its ability to mask the prime.

Mask ID under low versus high mask contrast. Responses to the mask were faster for consistent than for inconsistent trials, F_C (1, 5) = 49.02, p = .001, and these priming effects increased with SOA, F_{CxS} (3, 15) = 16.57, p < .001 (Fig. 19). Priming effects (Fig. 18, right panel) were larger by about 10 ms for weak than for strong masks, F_{MCFxC} (1, 5) = 9.67, p = .027. All other effects were nonsignificant, indicating that the time course of priming was similar under both masking functions. An analogous analysis showed that error rates were higher in inconsistent trials, F_C (1, 5) = 29.41, p = .003, and increased with longer SOA, F_S (3, 15) = 8.20, p = .002.

Mask ID under increasing versus decreasing mask contrast. In contrast to Experiment 1, both conditions now showed priming effects that increased with SOA (Fig. 18, right panel). Overall, response times were significantly faster for consistent than inconsistent trials, F_C (1, 5) = 51.16, p = .001, and this priming effect (Fig. 19) increased with SOA, F_{CxS} (3, 15) = 13.33, p < .001. Priming effects were larger under decreasing than under increasing mask contrast F_{CxMCF} (1, 5) = 16.02, p = .010, but there was no three-way interaction, and simple tests showed that priming effects increased with SOA for both mask-contrast functions, p = .042 and .009, respectively. An analogous analysis showed that error rates were higher in inconsistent trials, F_C (1, 5) = 21.26, p = .006, and increased with SOA, F_S (3, 15) = 11.15, p = .002. Priming effects increased faster with SOA under decreasing mask contrast, $F_{MCFxCxS}$ (3, 15) = 6.15, p < .006.

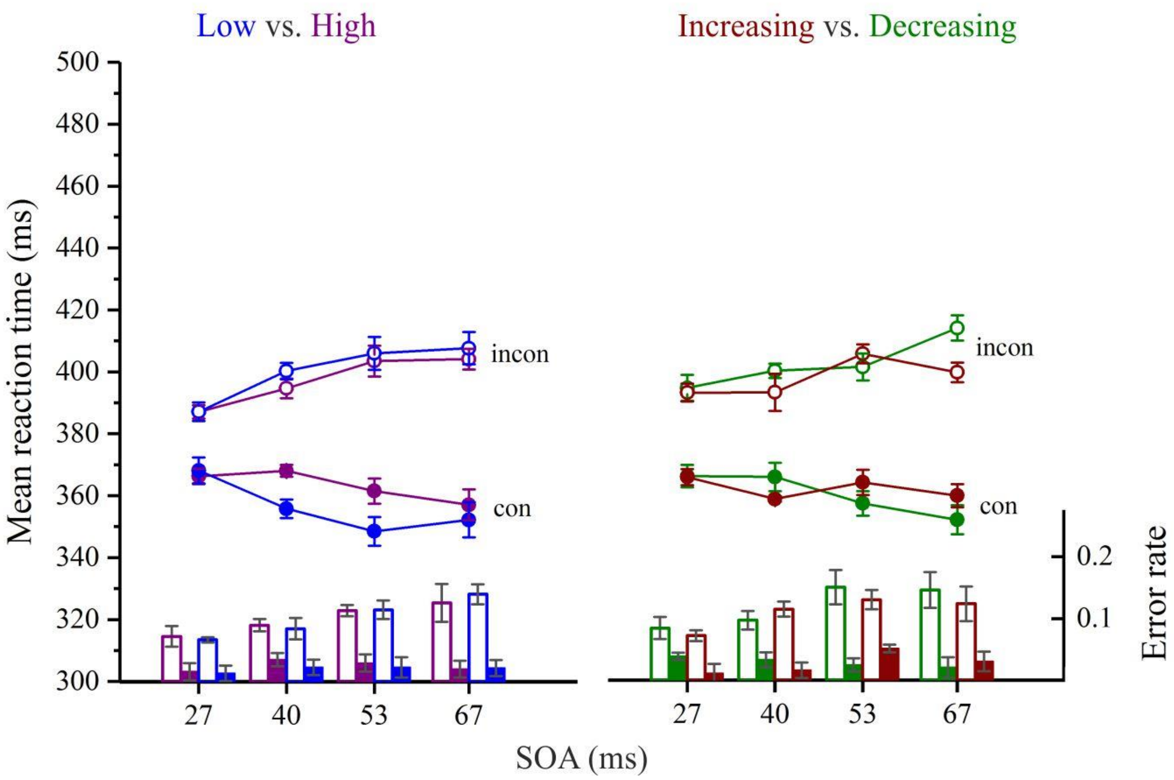

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Figure 19. Experiment 2. Mean reaction times and error rates for all four mask-contrast functions, and for consistent (con) and inconsistent (incon) trials.

Individual differences in masking and priming

As in Experiment 1, participants showed marked differences in prime discrimination performance (see Fig. 20). All participants performed better under low than under high mask contrast. Participant 1 performed at chance level throughout, Participant 4 was close to chance performance. Surprisingly, the remaining participants showed increasing performance with SOA for high-contrast masks but decreasing performance (type-B masking) for low-contrast masks. Under decreasing mask contrast, performance strongly increased with SOA from very low to very high values, conforming to the principle of connected endpoints. Under increasing mask contrast, there was a sharp dip in performance between the shortest two SOAs, after which performance remained constant. This variation in masking functions was in marked contrast to the priming effects, which increased with SOA in all participants. This was the case irrespective of whether prime discrimination performance was high or at chance, and no matter whether it increased or decreased with SOA.

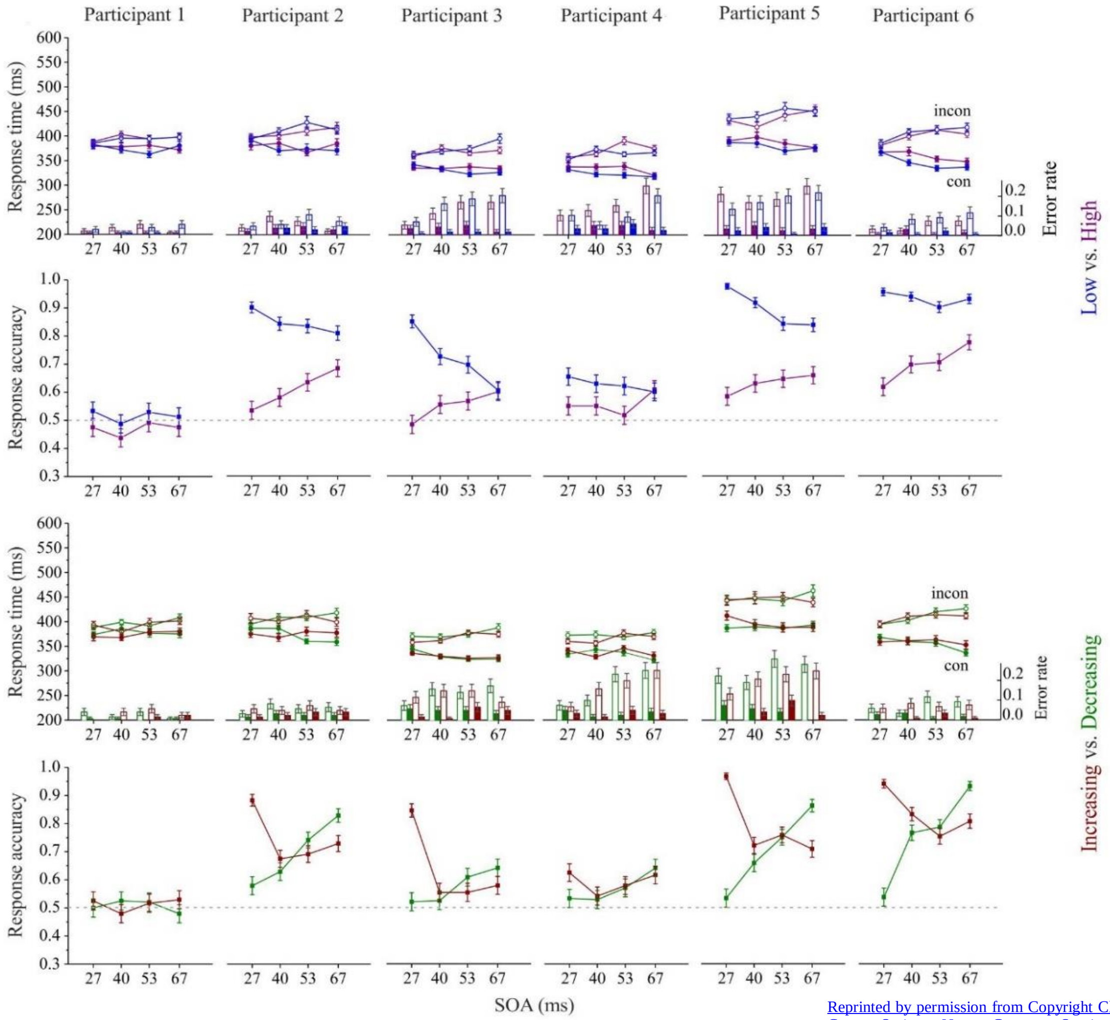

Figure 20. Results of each individual participant in Experiment 2.

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Conclusion

In Experiment 2 a double dissociation is successfully demonstrated (Vorberg et al., 2003): Priming effects increase with SOA no matter whether prime discrimination increases or decreases. Double dissociations are observable in a majority of participants. The key for this seems to be the use of uncoupled mask features (i.e., the separate manipulation of the mask's ability to reduce the visibility of the prime and its ability to activate the response). If those stimulus aspects are not decoupled, masking and priming are confounded, spoiling the chance of finding qualitatively different time courses even if the processes would be dissociable in principle. The data shows that custom-made MCFs can modulate masking functions while leaving priming functions intact and are able to accentuate dissociations between them. They are also able to provoke surprising new dissociation patterns: Under increasing versus decreasing MCFs, priming functions remain unchanged while the masking functions cross. This is actually evidence of an additional dissociation pattern: Priming effects are similar under increasing versus decreasing MCFs no matter which one leads to higher prime discrimination at a given SOA. A second surprise was that many participants showed spontaneous type-B masking under low-contrast masks, something ordinarily not observed in metacontrast masking of color stimuli. It is probably made possible by the special design of the stimuli: Whereas in previous studies color primes were surrounded by masks of either the same or different color, in these stimuli the masking is achieved primarily by the gray inner part of the stimulus. This setup reduces the color contrast between prime and mask (e.g., to red:gray instead of red:green) without reducing the luminance contrast of either stimulus. Luminance contrast is necessary for type-B metacontrast masking while mere color contrast is insufficient (Bowen et al., 1977), and metacontrast decreases with increasing color dissimilarity between mask and masked stimulus (McKeefry et al., 2005). Therefore, masking color primes by gray masks may allow type-B masking based on luminance contrast.

By randomly intermixing all stimulus conditions, the behavior of the masking functions becomes predictable because they now all conform to the principle of connected endpoints: They are forced to take crossed paths from strong masking at the shortest SOA to weak masking at the longest SOA (decreasing MCF), or vice versa (increasing MCF). The data therefore suggest that the shape of the masking function can largely be controlled by managing the degree of masking at the endpoints of the functions. The degree of control is limited, however, by the strong individual differences in the time-course of masking (Albrecht et al., 2010).

2.4 Experiment 3: MCFs with coupled and uncoupled mask features

In Experiment 1, priming effects and prime discrimination performance had comparable time courses under the different mask-contrast regimes, using shape stimuli. This failure to observe a double dissociation was suspected to be the result of the specific mask design, which confounded the mask's ability to activate a response with its ability to reduce the visibility of the prime. In Experiment 2, these two aspects of the mask were decoupled by separating it into two parts: an inner masking part and an outer response-activating part (in red or green). With these stimuli, a double dissociation was observable in the color domain.

It remains to be shown conclusively that the use of uncoupled mask features is really the key to the problem. Therefore, in Experiment 3 once again shape stimuli were applied and systematically compared under conditions of coupled and uncoupled mask features. Masks now consist of an inner part (responsible for metacontrast masking of the prime and varying in contrast) and an outer response-activating part. In *uncoupled masks,* the inner masking part is neutral in shape, and response activation is driven entirely by the shape of the outer part. This design should allow for a manipulation of the time course of the masking functions without affecting the priming functions in response times or error rates. In *coupled masks,* the outer part is neutral in shape, and response activation is driven entirely by the shape of the inner part. With this design, both response activation and masking should depend on the inner part alone and priming and masking effects should be associated.

2.4.1 Methods

Participants. Twelve students from the TUK (6 men; mean age 23.4 years; 1 left-handed) took part in eight one-hour sessions. All of them were naïve to the concept of the experiment and did not participate in Experiments 1 or 2. All participants had normal or corrected-to-normal vision and received 7 € per hour as payment. Each of them gave informed consent and was treated according to the ethical guidelines of the American

Psychological Association. After the final session, they were debriefed and received an explanation of the experiment.

Apparatus, stimuli, and procedure. The apparatus and procedure were identical to Experiments 1 and 2 except for new stimuli and for the sequence of blocks. Primes were small black squares and diamonds (0.04 cd/m²) with an edge length of 0.8 cm (0.76° of visual angle), appearing at fixation. Mask stimuli were about 2.2 cm in size (2.1° of visual angle).

There were two configurations of mask stimuli, employed in different sessions (see Fig. 14). Coupled masks were squares or diamonds surrounded by a circle (i.e., a neutral shape). Uncoupled masks were circles surrounded by either a square or a diamond. While the inner part varied in luminance (4.69, 12.60, 25.03, or 43.47 cd/m²) according to two mask-contrast functions (increasing or decreasing with SOA), the outer part was always presented at maximum contrast (black). As in Experiment 1, the inner part of the mask had a central cutout (both prime shapes superimposed) designed to mask both square and diamond primes by metacontrast.

Participants either responded to the shape of the mask (square or diamond, mask ID) or to the shape of the prime (prime ID). Two consecutive sessions always consisted of one session of the mask identification task followed by one session of the prime identification task. Pairs of sessions alternated between coupled and uncoupled mask conditions (or vice versa) – that is, the first two sessions employed coupled masks, the next two uncoupled masks, and so on.

Data treatment and statistical methods. Trimming of response times and data analysis proceeded as in Experiments 1 and 2. In mask ID, the trimming procedure eliminated 0.12 and 0.14 % of outlier trials for coupled and uncoupled masks, respectively. With only 60 and 120 trials per participant and ANOVA cell in mask identification and prime identification, respectively, standard errors per cell and subject of about 7.7 ms in response times, at most 6.5 percentage points in error rates, and at most 4.6 percentage points in prime identification accuracy were expected. This loss in precision was compensated by doubling the number of participants.

2.4.2 Results and Conclusion

Masking effects

As before, it is expected that prime discrimination performance would be increasing for decreasing mask contrast, and a decreasing or u-shaped masking function should be generated for increasing mask contrast, while priming effects should increase under both masking regimes. Crucially, this double dissociation should only occur for uncoupled masks, while priming and masking functions should be associated for coupled masks. Data was analyzed separately for the two mask types. This time, low and high MCFs were not included, only increasing and decreasing MCFs were compared under conditions of coupled and uncoupled masks.

Prime ID under increasing and decreasing mask contrast. The pattern of prime discrimination performance was similar for coupled and uncoupled masks (Fig. 21, left panel). Performance increased with SOA under decreasing mask contrast. Under increasing mask contrast, performance decreased between the shortest two SOAs and then remained constant. The different time-courses led to a significant interaction of mask function and SOA for coupled as well as uncoupled masks, F_{MCFxS} (3, 33) = 5.52 and 6.89, p = .031 and .014, respectively. For coupled masks, performance was significantly better under increasing mask contrast, F_{MCF} (1, 11) = 14.68, p = .003, a main effect not significant for uncoupled masks. For uncoupled masks, performance increased significantly with SOA, F_S (3, 33) = 3.51, p = .035. This main effect was not significant for coupled masks. Simple tests indicated that the SOA effect was significant in each of the four masking functions, all $p \leq .044$.

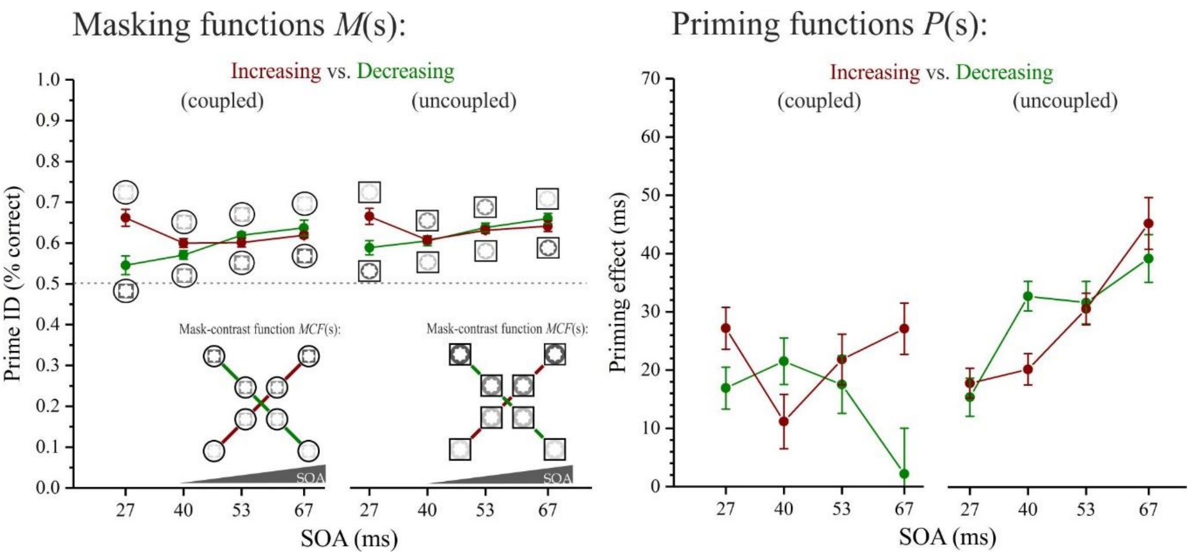

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Figure 21. Experiment 3. *Left panel*: Results of the prime identification task for all masking functions. Overall response accuracy is averaged across consistency. Inlays illustrate the respective masking condition. Only square masks are shown in the coupled condition, only circle masks are shown in the uncoupled condition. *Right panel*: Priming effects for all masking functions.

Priming effects

Mask ID under increasing versus decreasing mask contrast. For coupled masks, responses were faster in consistent than in inconsistent trials, F_C (1, 11) = 11.21, p = .007 (Fig. 22). This priming effect (Fig. 21, right panel) increased under conditions of increasing mask contrast (with the same dip at the 40-ms SOA that was observed in Experiment 1), and decreased under conditions of decreasing mask contrast, $F_{MCFxCxS}$ (3, 33) = 10.99, p < .001. In contrast to Experiment 1, but in tight agreement with the time-course of masking, this decrease continues until the priming effect virtually disappears. Averaged across SOA, the priming effect was slightly larger under increasing mask contrast, F_{MCFxC} (1, 11) = 18.73, p = .001. Overall response times increased with SOA for decreasing mask contrast but decreased with increasing mask contrast, forming an x-shaped pattern, F_{MCFxS} (3, 33) = 283.65, p < .001. Overall, response time was a u-shaped function of SOA, F_S (3, 33) = 145.05, p < .001. The error rates follow a similar pattern, with more errors in inconsistent than consistent trials, F_C (1, 11) = 7.68, p = .018, and at the shortest and longest SOA, F_S (3, 33) = 14.67, p < .001. These priming effects were larger under increasing mask contrast, F_{MCFxC} (1, 11) = 10.39, p = .008, and differed across

SOAs, F_{CxS} (3, 33) = 6.07, p = .002. ANOVAs performed separately for each mask-contrast function confirmed significant priming effects in response times for increasing as well as decreasing mask-contrast functions, F_C (1, 11) = 16.55 and 6.32, p = .002 and .029, significant main effects of SOA, F_S (3, 33) = 243.99 and 211.86, both p < .001, and significant interactions of SOA and consistency, F_{CxS} (3, 33) = 8.04 and 5.09, p < .001 and p = .016, respectively.

For uncoupled masks, responses were faster for consistent than for inconsistent trials, F_C (1, 11) = 102.70, p < .001 (Fig. 22), and this priming effect increased with SOA, F_{CxS} (3, 33) = 26.98, p < .001 (Fig. 21, right panel). Overall, response times increased with SOA, F_S (3, 36) = 15.32, p < .001. Although priming functions under increasing and decreasing mask contrast look quite similar, there is a significant three-way interaction, $F_{MCFxCxS}$ (3, 33) = 3.80, p = .019, and an interaction of mask-contrast function with SOA, F_{MCFxS} (3, 33) = 5.69, p = .003. The error rates follow a similar pattern, with more errors in inconsistent than consistent trials, F_C (1, 11) = 29.11, p < .001, and errors increasing with SOA in inconsistent trials only, F_{CxS} (3, 33) = 10.12, p < .001, F_S (3, 33) = 10.52, p < .001. Error rates were slightly higher under increasing mask contrast, F_{MCF} (1, 11) = 5.26, p = .043. ANOVAs performed separately for each mask-contrast function confirmed the finding of significant priming effects in response times for increasing as well as decreasing mask-contrast functions, F_C (1, 11) = 111.04 and 74.58, both p < .001, significant main effects of SOA, F_S (3, 33) = 3.64 and 13.26, p = .022 and < .001, and significant interactions of SOA and consistency, F_{CxS} (3, 33) = 13.77 and 18.44, both ps < .001, respectively. Overall, responses were about 50 ms faster for uncoupled than for coupled masks, t(11) = 10.67, p < .001, reflecting the generally higher contrast of the imperative stimulus.

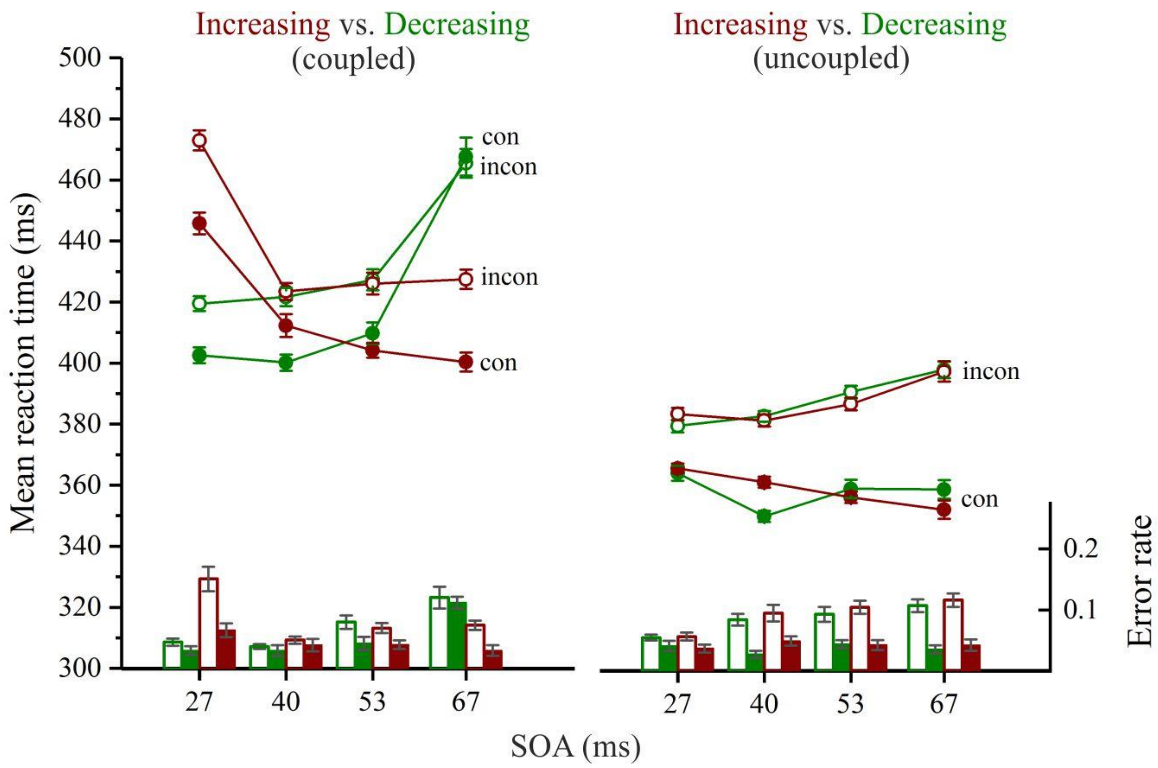

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Figure 22. Experiment 3. Mean reaction times and error rates for all mask-contrast functions and for coupled and uncoupled stimuli.

Individual differences in masking and priming

Again, participants showed remarkable homogeneity in their priming effects (see Fig. 23). For uncoupled masks, most participants showed the characteristic response-time pattern where priming effects increase with SOA. For coupled masks, most of them showed the crossover pattern characteristic of Experiment 1, with elevated response times when the imperative stimulus was low in contrast, and a dip in priming effects at the 40-ms SOA. Again, participants were much more variable in their masking functions. Most participants performed close to chance level throughout. The remaining participants showed increasing accuracy for decreasing mask contrast, and u-shaped masking functions for increasing mask contrast.

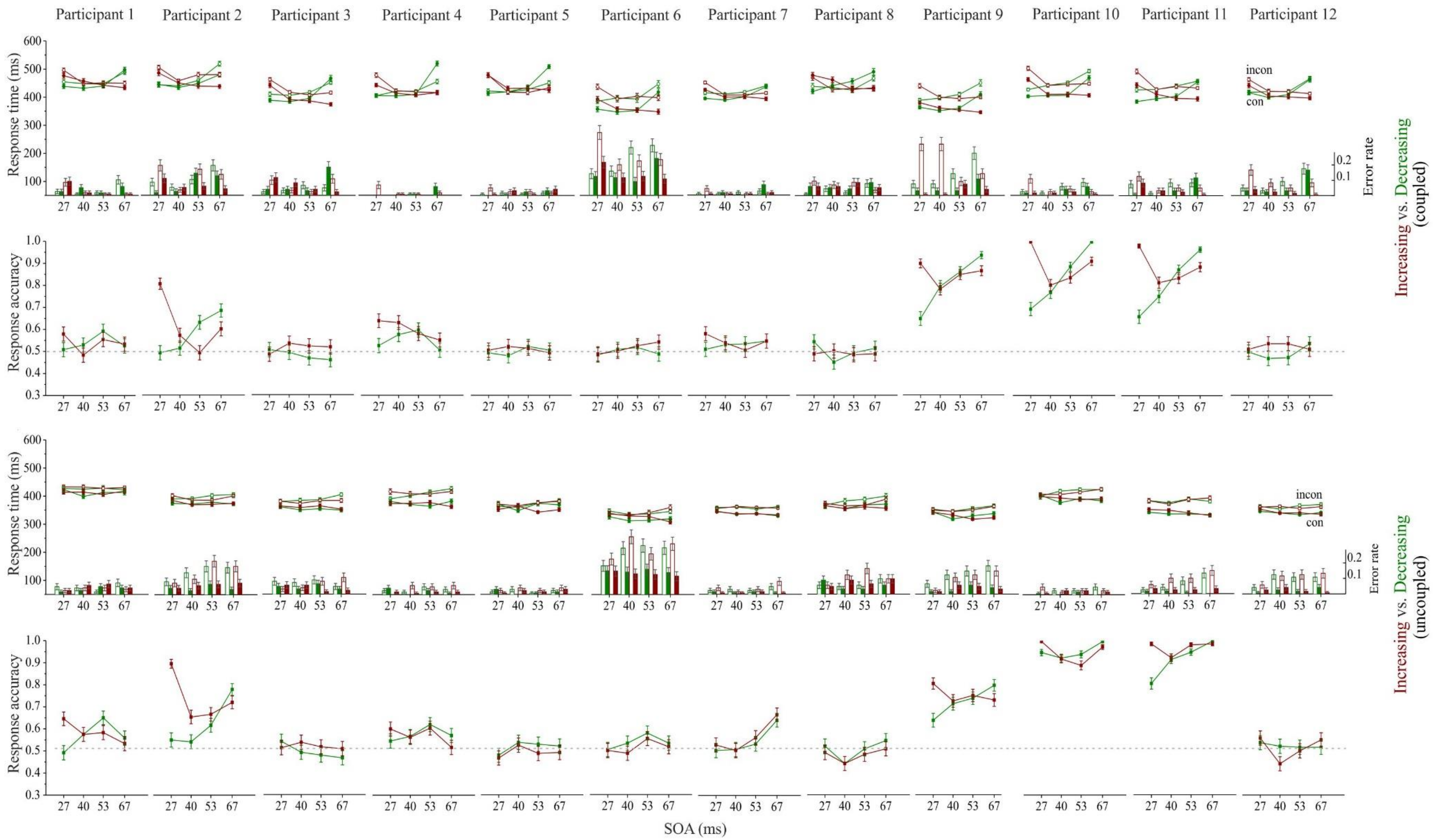

Figure 23. Results of each participant in Experiment 3.

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Conclusion

Experiment 3 clearly shows that in order to use induced dissociations, it is necessary to decouple the ability of the imperative stimulus to mask the prime from its ability to activate the response. When those two aspects of the mask were confounded, a data pattern as in Experiment 1 where priming and masking were closely associated is obtained. In contrast, when those two aspects were decoupled, the data pattern of Experiment 2 was obtained, where priming effects increased despite decreasing performance in prime discrimination (double dissociation). In addition, it is demonstrated that priming effects are similar under increasing versus decreasing MCFs no matter which one leads to higher prime discrimination performance at a given SOA.

All these principles can be demonstrated in performance levels of individual participants. However, the analysis of single subjects reveals limitations of this new method. Participants differ strongly in the overall shape of their masking functions, and many of them operate close to chance level when trying to discriminate the prime. They generate floor effects that spoil any chance of a double dissociation, but of course still give rise to a simple dissociation: large priming effects in the absence of prime discrimination. Those participants that did respond to the change of the mask-contrast function showed double dissociation patterns where priming effects increased no matter whether prime discrimination increased or decreased (Vorberg et al., 2003).

Why was masking so strong in so many participants even under conditions where the metacontrast mask was at minimal contrast? It is possible that the composite stimuli which were used as masks not only generate metacontrast from the inner part of the stimulus but also object substitution masking from the outer part, a form of masking where the to-be-masked stimulus is replaced with surrounding stimuli that are not immediately adjacent to its contours (Di Lollo et al., 2000; Enns & Di Lollo, 1997, 2000). Our mask-contrast functions only control the amount of metacontrast but would still allow for substitution masking.

2.5 Discussion Part I

Uniqueness of (induced) double dissociations. In this set of experiments, the technique of induced dissociations was successfully applied, demonstrating that an indirect measures of stimulus processing (e.g., response priming effects) and direct measures of stimulus awareness (e.g., prime discrimination performance) can be forced to reveal a double-dissociated data pattern. The custom-made MCFs provoked qualitatively different time courses of the masking functions while the priming effects were unaffected by this method. Notably, different dissociation patterns are demonstrated for shape stimuli as well as within the domain of color where double dissociations between metacontrast masking and priming have not been observed before. In addition to the demonstration of simple dissociations and some kind of new dissociation pattern, where priming functions remain similar under increasing and decreasing MCFs, double dissociations as one of the rarest but strongest type of dissociations were observed.

As argued (Section 1.4 "Double dissociations"), double dissociations circumvent the classical problem of demonstrating the absence of awareness (zero-awareness criterion, T. Schmidt & Vorberg, 2006) as a major drawback of simple dissociations. Since double dissociations show opposite time courses of two measures, they do not require zero awareness of the critical stimulus. Hence, they exempted themselves from such restrictions and are of immediate theoretical interest because they summarily refute all models which assume that both direct and indirect measures depend on only one source of information (T. Schmidt & Vorberg, 2006). Double dissociations, regardless of whether they are induced or occur naturally, are informative since both types most convincingly demonstrate that perception can occur without awareness, but with no need to show a value of zero for the critical stimulus. More crucially, induced double dissociations have a decisive advantage over naturally occurring double dissociations: they are easier to find. Usually, type-B masking functions with a u-shaped curve only occur under specific circumstances in metacontrast masking (Breitmeyer & Öğmen, 2006; see also F. Schmidt et al., 2011). With this new technique, parameters are carefully adjusted to systematically produce different masking functions with increasing (type-A), decreasing or u-shaped (type-B) curves.

Individual data versus averaged data. One key feature of custom-made MCFs is that they can strongly accentuate the masking functions, most impressively observable at the level of individual observers: While priming effects are homogeneous across participants, the variations in the amount and time-course of metacontrast masking are huge – so huge, in fact, that they could never be remedied by adjusting prime or mask contrast for individual observers, because there are floor as well as ceiling effects under minimum as well as maximum mask contrast. Albrecht and colleagues (Albrecht et al., 2010; Albrecht & Mattler, 2010, 2012, 2016) have shown that metacontrast masking functions are idiosyncratic and stable over time, but as currently shown also malleable to some degree. Thus, the diverse microstructure of masking effects is best revealed at the level of individual observers, which is why these effects cannot be depicted on an averaged data level in the same way. This generally raises the question whether masking functions from individual observers should ever be averaged, at least not as uncritically as is customary in the masked-priming literature. Since priming effects are homogeneous over time and observers, averaging priming data is less critical. Nevertheless, the evaluation of individual data can be more informative, and the microstructure of priming effects can give further insights into underlying processes. The strength of this method is most impressively demonstrated at the individual level. Consequently, averaged data as the only data source could have led to misleading assumptions. In general, it is advisable to measure masking and priming with high precision in each participant instead of a large number of participants with low precision and then averaging the results (*Small-N design*, Smith & Little, 2018). Measures with high precision require a large number of observations per subject and condition. As recommended, there should be at least a number of 60 repeated measures per subject and condition (r = 60 F. Schmidt et al., 2011; Smith & Little, 2018).

Coupled versus uncoupled stimuli. In order to demonstrate dissociative patterns of priming and masking at an individual level, one crucial criterion must necessarily be met. The technique of induced dissociations requires stimuli that separate the ability to mask the prime from the ability to activate a response. If those two aspects of the imperative stimulus remain confounded (coupled masks), priming effects will be compromised in exactly those conditions where prime visibility is also low, and no dissociation between the two measures can be expected.[30] But when composite stimuli are used in which the part that induces masking (e.g., luminance contrast of a metacontrast ring mask) is varied

[30] In the present experiments, the 40-ms SOA shows the strongest masking effect. This is in line with Breitmeyer and Öğmen’s (2006) conclusion that the optimal SOA for metacontrast is between 10 and 40 ms (cf. Macknik & Livingstone, 1998; van Aalderen-Smeets et al., 2006).

independently from the part that activates the response (e.g., an additional shape or color part), masking can be varied without affecting the time-course of response priming (uncoupled masks). This procedure most effectively leads to smooth and regular priming functions that increase with SOA in basically all observers, no matter whether prime visibility is high, low, increasing, or decreasing with SOA (cf. Vorberg et al., 2003).

Why do coupled masks influence response priming in the first place? Response priming is best described as a conflict between responses elicited in turn by the prime and target. Accumulator models of response priming assume that after the prime has begun to activate its associated response, the target will activate either the same response (consistent trial) or the opposite response (inconsistent trial), which requires counteracting the previous influence of the prime. T. Schmidt and F. Schmidt (2018; cf. Vorberg et al., 2003; Schubert et al., 2013) present an accumulator model for the case that primes and targets have different rates of response activation depending on prime and target strength. This model predicts (1) that response times decrease with target strength, and (2) that priming effects increase with prime strength but decrease with target strength (because a stronger target is quicker in counteracting the prime). In coupled masks, high mask contrast would thus lead to strong masking as well as reduced priming, whereas low mask contrast would lead to weak masking and increased priming. The model also explains why response times are generally faster under uncoupled than under coupled conditions: uncoupled masks have a response-activating part that is always at maximum contrast, whereas coupled masks vary between minimum and maximum values.

Post hoc classification of trials. One strength of the method is that it does not rely on post hoc classification of trials into "aware" and "unaware" classes. Post hoc classification has become a popular approach to unconscious perception (e.g., Avneon & Lamy, 2018; Ro, 2008; Sergent et al., 2005; Van den Bussche et al., 2013), but the correlational nature of this method generates a number of problems. As an example, Van den Bussche et al. (2013) employed a priming version of the Stroop paradigm and used subjective prime visibility ratings to categorize individual trials as “conscious”, “uncertain”, or “unconscious”. On each trial, participants first performed a speeded response to the target masked by forward and backward masks, and then rated their confidence in identifying the prime word. Because the two primes always appeared under physically identical conditions, awareness was not controlled experimentally, and all results were derived by sorting the participants' judgments into categories post hoc. After a somewhat worrisome scheme that excluded 19 of the 56 participants, priming effects were found in all three rating categories, but were most prominent for trials rated as “conscious”. The authors conclude that the magnitudes of “priming effects are highly dependent on prime visibility” (Desender & Van Den Bussche, 2012, p. 1572; see also Van den Bussche et al., 2010, 2013; Avneon & Lamy, 2018). This method is unsatisfactory for a number of reasons. First, it replaces the experimental control of prime visibility with a correlational approach. Second, it suffers from regression to the mean: If correlations between visibility ratings and priming effects are not downright perfect, sampling error will cause priming effects to be too similar to each other, overestimating the amount of priming in the "unconscious" selection (Shanks, 2017). Third, all sources of variation that are common to both measures (early ones such as signal fluctuations in the early visual system, late ones such as attention or decision noise) would create a correlation between priming and visibility, so no conclusion can be made that awareness causes priming (let alone the stronger conclusion that awareness is necessary for priming). The technique of induced dissociations with uncoupled masks shows that prime visibility (i.e., visual awareness) can be experimentally controlled without confounding it with prime or target strength. Moreover, the repeated demonstration of double dissociations between priming and masking immediately refutes the idea that awareness of the prime is necessary for response priming.[31]

Methodological considerations and limitations. In addition to the already mentioned aspects (e.g., measurements with high precision, uncoupled stimuli, problems of post hoc classification), there are further factors that should be considered using the technique of induced dissociations. (1) MCFs must be assigned beforehand; they cannot be assembled post hoc. Otherwise, the procedure would be correlative instead of experimental, and likely not lead to replicable results. (2) MCFs should be intermixed across trials so that the local context of visibility is the same for all functions. It also ensures that the principle of connected endpoints is rationally exploited. (3) Prime visibility should never be reduced by simply degrading the prime because this would result in reduced priming as well (F. Schmidt et al., 2011; T. Schmidt & Schmidt, 2018). Instead, masking techniques should be used to control prime visibility, being aware that forward

[31] However, this might be difficult to demonstrate with pattern masks, which seem to interfere with prime processing (Wernicke & Mattler, 2019). Most successful demonstrations of double dissociations employ metacontrast masks.

masks interfere with response priming in both pattern and metacontrast masking (Becker & Mattler, 2019), and that pattern masks in general interfere with response priming more strongly than metacontrast masks (Wernicke & Mattler, 2019). (4) Within the present study, mask-contrast functions varied monotonically with SOA. Nevertheless, it is imaginable that MCFs might also be nonmonotonic (e.g., u-shaped, inversely u-shaped). The procedure of custom-made MCFs can be generalized to designs with more than two measures and more than two independent variables. Instead of using only two variables (e.g., mask contrast and SOA), a third factor (e.g., mask duration) might be added. Then mask contrast and duration could increase over prime-mask SOA or could decrease over time. Actually, the procedure of conjoining two (or more) independent variables (here, mask contrast and SOA) in one *supervariable* comes at an interpretational cost. This means that the independent variables are deliberately confounded and cannot be interpreted separately. For that reason, a decrease in visibility that is for instance only brought about by a manipulation of mask contrast but would not occur otherwise should not be called type-B masking. That term should be reserved for MCFs that are constant across SOA and can be freely interpreted without reference to an additional variable. But even so, a double dissociation is always informative, no matter whether it arises from a cunning manipulation of supervariables or more "naturally" from a single variable like contrast or SOA. (5) An equivalent to this method is to realize all combinations of independent variables (here 16 conditions, 4 SOAs: 27 ms, 40 ms, 53 ms, 67 ms x 4 mask contrasts; high, low, increasing, decreasing). As a result, within data analysis, specific combinations (e.g., vertical, horizontal, or diagonal) can be compared with each other.

General utility. Induced double dissociations can be applied to objective as well as subjective measures, like discrimination tasks, same-different and oddity tasks, visibility and confidence ratings, ratings on the Perceptual Awareness Scale (e.g., Ramsøy & Overgaard, 2004), or ratings on customized scales. Even though all these methods are designed to measure some aspect of awareness of a critical stimulus, they all likely differ in criterion content (Kahneman, 1968), and thus in the way visual information is actually used by the observer to perform the task. Consequently, different methods will generally not lead to interchangeable results (Breitmeyer & Öğmen, 2006; Sackur, 2013; Sandberg et al., 2010), claims that one or the other were some kind of "gold standard" notwithstanding. Visual awareness is a multi-faceted construct, and observers can be aware of some stimulus features without being aware of others (Albrecht & Mattler, 2016; Koster et al., 2020). Therefore, which kind of measure is applied should be carefully considered and mostly depends on the research question of interest (Cheesman & Merikle, 1984; F. Schmidt et al., 2011). Since both objective and subjective measures give potentially interesting information on visual awareness, one type of measure cannot replace the other. Ideally, they should be used in tandem (F. Schmidt et al., 2011).

While the technique of induced dissociations is used here only in the context of masked response priming, the technique is of general utility. The trick is always to treat one independent variable as a function of another independent variable, and then to pit several such functions against each other to provoke dissociations between dependent variables. For instance, in masked semantic priming, mask contrast could be made a function of prime characteristics known to influence the priming effect, such as word frequency or semantic relatedness. In techniques based on binocular rivalry, such as continuous flash suppression, many characteristics of the mask and the to-be-masked stimulus can be varied independently and parametrically (such as temporal frequency, spatial frequency, color or luminance contrast), including changes over the time-course of a trial. In experimental medicine, induced double dissociations may be employed to dissociate the effects of two drugs on two physiological functions by making one dosage an increasing or decreasing function of the other dosage. The wealth of exotic experimental designs is expanded by this method.

3. Experiments Part II: Double dissociations under pressure[32]

3.1 Introduction

The technique of induced dissociations has demonstrated that masking functions can be bent into a desired shape while priming functions remain unaffected, still increasing over time. Consequently, a double-dissociated data pattern between a direct measure of stimulus awareness and an indirect measure of stimulus processing can be formed. The fascinating fact that double dissociations can be induced by systematic manipulations of independent variables, even though they otherwise only occur naturally under very specific conditions, motivated the second set of experiments. I further wanted to test the limits of priming and masking effects in terms of a double dissociation, investigating how these effects will change when tested under different task settings and experimental conditions. Does a double dissociation occur in any of the experimental conditions? If so, which conditions and factors must be considered in order to obtain a (naturally occurring) double dissociation? Thereby I hoped to gain further useful knowledge for induced dissociations as well.

In three experiments on masked response priming, a situation was created where participants performed one, two or three tasks within one trial and session. In this context, an objective prime discrimination task and a subjective ratings task (using the Perceptual Awareness Scale of Ramsøy & Overgaard, 2004) served as direct measures of prime awareness. Direct measures were applied either within the same trial as the indirect response priming task (dual-or triple task) or separated in different trials and sessions (single task). This procedure (where either only one or several tasks had to be performed within the same trial) places different cognitive demands on the observer. For this reason, different outcomes of the direct and indirect measure (i.e., masking and priming functions, respectively) were expected for the three types of tasks. This expectation is consistent with the findings of Lamy, Carmel, and Peremen (2017). In this response priming study they

[32] The experimental sections mainly correspond with my manuscript submitted for publication: Biafora, M., & Schmidt, T. (2021). *Juggling too many balls at once: Qualitatively different effects when measuring priming and masking in single, dual, and triple tasks* [Manuscript submitted for publication]. Department of psychology, University of Kaiserslautern. Some parts contain the exact wording and/or figures; other parts are adjusted to my present thesis.

give a table of absolute response times in a dual-task situation, revealing that the average response times to the target are about 150 ms longer than usually obtained in single response-priming tasks. Actually, as one would expect, the serial performance of more than one task seems to require overlapping mental operations with a higher memory load and more cognitive control relative to single tasks (Pashler, 1989, 1994a, 1994b). Therefore, one critical question was whether a multitask situation (dual- and triple task) provide the same conditions for fast response activation, considered as a specific feature of response priming, as a single task.

One approach that explains priming effects as a result of fast (feedforward) response activation without conscious control is Rapid-Chase Theory (T. Schmidt et al., 2006, 2011; see also T. Schmidt, 2014). Based on the observation that participants use visual information in different ways to perform the task at hand (criterion content, Kahneman, 1968; see also Albrecht & Mattler, 2012; Koster et al., 2020), objective and subjective measures of visual awareness were applied and compared for possible dissociations. This should provide further understanding whether both measures react equally sensitively to changes in stimulus conditions, and whether they are equally valid for measuring visual awareness of the critical stimulus.

In the following sections, an overview of Rapid-Chase Theory (T. Schmidt et al., 2006, 2011; see also T. Schmidt, 2014), different types of tasks and measures for visual awareness, as well as Kahneman's (1968) understanding of criterion content is given.

3.1.1 Rapid-Chase Theory

Rapid-Chase Theory was introduced in 2006 by T. Schmidt, Niehaus and Nagel (formally described in more detail by T. Schmidt, 2014; see also T. Schmidt et al., 2011)[33] and explains the positive response priming effect as rapid and automatized response activation. This approach is fundamentally based on the assumptions of *direct parameter specification* (*DPS*, Neumann, 1990; Neumann & Klotz, 1994; Scharlau & Ansorge, 2003; Ansorge, 2004; Ansorge & Neumann, 2005). In this context, participants acquire automatized rules of the stimulus-response mapping during a practice phase (e.g., left key for a diamond stimulus, right key for a square stimulus). After this phase, a diamond-

[33] In contrast to the APA citation style, the sources are omitted in the following sections for better readability. Subsequently, the named authors are for reference.

shaped stimulus is sufficient to directly activate the response assigned to it (left keypress), "without … giving rise to a corresponding mental representation …" (Neumann, 1990, p. 212). According to the DPS, response priming effects are assumed to occur because the critical prime feature triggers the same response process that is supposed to be activated later by the target. Rapid-Chase Theory expands the *DPS* model with the finding that each visual stimulus triggers a wave of neuronal responses which rapidly spreads from visual to motor areas in the cortex (e.g., Bullier, 2001; Lamme & Roelfsema, 2000; Thorpe et al., 1996; VanRullen & Thorpe, 2002). Since this first wave of neural activation is very fast, it is assumed to start as a pure feedforward process, which, however, does not generate visual awareness (Lamme and coworkers, 2000; 2002). In order to generate visual awareness, subsequent neuronal feedback mechanisms are required (Di Lollo et al., 2000; Lamme & Roelfsema, 2000).

In combination with response priming, the Rapid-Chase approach assumes that successively presented stimuli (e.g., prime – target) elicit fast feedforward sweeps in the visuomotor system of the same manner; consequently, in strict sequence, without any temporal overlap and with no need of conscious control or the integration of recurrent processes[34] (T. Schmidt, 2014; see also T. Schmidt et al., 2006, 2011). During response priming, the prime constitutes the first visual input in the prime-target sequence and its signal reaches motor areas first. Here, the prime signal activates the motor response assigned to it (e.g., right keypress) and drives on the response on its own, until the target signal arrives within this 'rapid chase' of feedforward processing. Now, the target can continue the motor response in consistent trials (e.g., square – square) or redirect the response (if the stimuli are inconsistent, e.g., square – diamond). The shorter the prime-target SOA, the sooner the target can take up the chase, while at longer SOAs (up to 100 ms) the prime has more time to control the response on its own. Since this process is assumed to be fast and purely feedforward, visual awareness is not generated (T. Schmidt et al., 2006, 2011; see also Vath & Schmidt, 2007). Hence, feedforward activated response priming effects can increase over time, triggered by the critical stimulus feature of the prime while the stimulus information must not necessarily be perceived as clearly visible. As a corollary, prime awareness can decrease over time while priming effects can still increase over prime-target SOA, forming a double dissociation.

[34] Since "there is little or no time to integrate feedback from other cells" (T. Schmidt et al., 2006, p. 1005; see also Bullier, 2001; VanRullen & Koch, 2003; VanRullen & Thorpe, 2002).

Thomas Schmidt (T. Schmidt, 2014; see also T. Schmidt et al., 2011, 2006) formulated three feedforward criteria of feedforward systems[35]:

(1) *Initiation criterion*
(2) *Takeover criterion*
(3) *Independence criterion*

The *initiation criterion* (1) describes that the first visuomotor response activity is initiated and solely controlled by the prime that triggers the onset and direction of the response, because first, in inconsistent trials error rate increases with SOA while fewer errors occur under conditions of consistent trials; second, errors are as fast as the fastest correct responses, and third, the fastest responses always follow the identity of the prime (i.e., they are always correct when the prime is consistent and always incorrect when it is inconsistent; Panis & Schmidt, 2016). The *takeover criterion* (2) dictates that the target signal must be able to influence the response to the prime before its processing is completed. This ensures "that the time order of motor output matches the time order of the stimuli controlling that output" (Vath & Schmidt, 2007, p. 198). The last *independence criterion* (3) describes that the motor responses initially depend on prime characteristics only and are therefore independent of all target characteristics[36].

[35] Note that (1) "*not all rapid-chase systems are feedforward systems* [emphasis by the author] … [,] because a rapid-chase system is classified on the basis of stimulus input and motor output, not of neuronal processes. Therefore, a rapid-chase system can tolerate some local recurrent processing …" (T. Schmidt, 2014, p. 6). (2) "Rapid-chase processing only proposes that the first sweep [of prime activation] must be independent of the second sweep [of target processing], but not vice versa" (T. Schmidt, 2014, p. 6). Hence, the initial processing has to be exclusively controlled by the prime, whereas later processing does not have to be exclusively controlled by the target (T. Schmidt, 2014).

[36] According to T. Schmidt (2014), "this has first been demonstrated in the time course of lateralized readiness potentials [LRPs] in the EEG …" (p. 2) (e.g., Eimer & Schlaghecken, 1998; Klotz et al., 2007; Vath & Schmidt, 2007) where a biphasic pattern showed that the initial response activation was time-locked to the prime and developed in the direction specified by it. This pattern was followed by a relative activation of the opposite response, leading to the correct response to the target for inconsistent trials. The motor impact of the prime was equally effective demonstrated by primed pointing movements (e.g., T. Schmidt, 2002).

3.1.2 Single and multiple tasks

In most response priming studies, direct and indirect measures are applied together within the same trial and session as in multiple tasks (e.g., dual or triple tasks) or separately as in single task-settings. Generally, no more than three tasks are carried out within one trial; otherwise, the cognitive effort might be too high for the observer (especially because the priming task requires fast responses that should be given as accurately as possible).

As mentioned, within a *single task* design direct and indirect tasks are performed in separate trials and sessions (e.g., Vorberg et al., 2003). Hence, an indirect measure of stimulus processing (e.g., speeded keypress responses to target shape) is realized in one trial and session, whereas a direct task to measure stimulus awareness is performed in another trial and session. In general, direct tasks use either objective measures (e.g., yes-no detection or discrimination) or subjective measures (e.g., ratings on stimulus brightness, clarity of impression)[37]. In a *dual task*, both direct and indirect measures are applied within the same trial and session (e.g., Lamy et al., 2017). Therefore, participants give two responses in a row, e.g., a speeded response to the target (indirect task) and a non-speeded response to the prime (e.g., direct objective discrimination task). Alternatively, a subjective measure could be used as direct task (e.g., PAS, Ramsøy & Overgaard, 2004). Under conditions of a *triple task*, participants perform three tasks in a row (e.g., Peremen & Lamy, 2014). Therefore, participants may perform a priming task with speeded responses to a target (indirect measure), followed by an objective prime discrimination task and an additional subjective prime awareness rating (both direct measures).

There is an ongoing debate about how awareness should be measured in the dissociation paradigm, and therefore whether direct and indirect measures should be applied separately or together within the same trial and session. While some research groups (e.g., Lamy et al., 2017; Peremen & Lamy, 2014; Van den Bussche et al., 2013) argue that double dissociations observed between response priming and prime visibility under single-task conditions might be the result of a measurement artifact[38], others (e.g., F.

[37] See Section 3.1.3 “Measures of visual awareness” for more details.

[38] As argued by Peremen and Lamy (2014), “differences in attention rather than in the conscious perception …”(p. 23) of the observers might account for the dissociation between the tasks, because observers attend to the prime in the direct (awareness) task and to the target in the indirect task.

Schmidt et al., 2011; T. Schmidt & Vorberg, 2006; Vorberg et al., 2003) in turn emphasize the benefits of separated tasks as it can avoid a mismatch between direct and indirect measures (*D-I mismatch*, T. Schmidt & Vorberg, 2006). As suggested by Reingold and Merikle (1988), the tasks used for the direct (*D*) and indirect (*I*) measure should be directly comparable (T. Schmidt & Vorberg, 2006). Within single tasks, direct tasks with non-speeded responses to the prime are performed separately from indirect tasks with speeded responses to the target, which is why each task is optimized for directing the attentional resources to the task-relevant stimulus (to the prime in the direct task, and to the target in the indirect task). This should facilitate prime identification as compared to a single target-identification task where the prime can be ignored. Within multiple tasks, direct and indirect tasks are performed within the same trial, which is why sensory attention has to be split between the stimuli, rendering any finding of low prime identification performance less convincing. Rather, multiple tasks require observers to simultaneously store all necessary stimulus information until the specific response to the stimulus is required, consequently leading to a higher working memory load. Hence, the question arises whether single and multiple tasks (e.g., dual or triple tasks) within response priming experiments provide the same conditions for fast response activation as expected under Rapid-Chase Theory. As noted at the beginning, a simple comparison of averaged response times under conditions of singly performed priming tasks (as usually obtained in experiments of our research group) with the response time results under dual-task conditions of Lamy et al. (2017) revealed that responses to the target were substantially slower in dual tasks. This massive delay suggests that observers hold all stimulus information in memory and perform all task based on the same memory representation. Possible dissociations might get lost because responses are no longer activated automatically by simple feedforward processes as expected under Rapid-Chase Theory. Rather, in multiple task-settings, divided attention between the tasks places higher demands on cognitive control (Pashler, 1989, 1994b)[39], more likely causing slower

[39] In Pashler's experiment (1989) only the second task involves visual processing of a stimulus, while the first stimulus required a speeded response to a tone, deciding whether the tone was high or low in pitch. The tone was followed by an array of eight digits and a subsequent mask. Participants made a non-speeded response determining the highest digit in this array. Although this method is different to our procedure of visual response priming, it highlights the fact that multiple tasks always lead to higher cognitive costs than single tasks.

reaction times or impaired performances in prime identification (e.g., switch-costs, task-shift costs, and task-set reconfiguration costs; Kiesel et al., 2007; Pashler et al., 2001; Waszak et al., 2003).

3.1.3 Measures of visual awareness

The debate about how awareness should be measured within the dissociation paradigm includes the controversy whether one class of measures is better suited and should be considered as “gold standard”. This debate mostly distinguished between two types of direct measures: objective and subjective measures.

In *objective measures,* participants respond to a specific stimulus aspect, which is the feature of interest; for instance the shape, the color or the location of a stimulus. Usually, the observer’s performance is specified by some objective variable, such as response accuracy (e.g., level of correct responses). There are several different tasks for objective measures. In *yes-no detection* tasks, participants indicate whether the critical stimulus is present or absent (e.g., Vorberg et al., 2003), while in *discrimination* tasks observers are encouraged to differentiate between stimuli and their critical stimulus information. Participants may have to specify whether the presented stimulus was a square or diamond (e.g., Biafora & Schmidt, 2020). In *two-alternative forced choice* tasks, participants might be confronted with the situation where two stimuli (e.g., a picture of a spider and a mushroom) are presented at different time intervals and locations (e.g., left and right), deciding which picture was presented first (e.g., Haberkamp et al., 2018) or which one is the target. Hence, in objective measures participants’ responses can be compared with the actual stimulus and are therefore classifiable as correct or incorrect.

In *subjective measures*, participants mostly report an internal state of perception; thus, stimulus parameters are not validated externally (e.g., subjectively-defined thresholds or subjective thresholds, Cheesman & Merikle, 1984, 1986). Hence, observers might rate the clarity of stimulus impression on a dichotomous rating scale (e.g., seen vs. not seen) or on a gradual scale with categories of predefined values such as the Perceptual Awareness Scale (Ramsøy & Overgaard, 2004). Here, the visual impression of the observer is assessed on a four-point rating scale, for example by pressing the digit keys from 1 to 4. The scale categories might be "1: no experience”, "2: brief glimpse", "3: almost clear experience", and "4: clear experience", as originally created by Ramsøy and Overgaard (2004). Other possible alternatives might be ratings on stimulus brightness (e.g., T.

Schmidt et al., 2010), ratings of confidence in correct identification (e.g., Cheesman & Merikle, 1986), or placing a wager on having performed the task correctly according to the method of post-decision wagering[40] (*PDW,* Persaud et al., 2007). Actually, different types of direct measures not only differ in their object of measurement (e.g., the ability to distinguish shapes, the subjective confidence in the decision) but probably also in their criterion content – i.e., the information that the observer is actually using when performing the task (Kahneman, 1968). While objective measures are based on physical stimulus characteristics (e.g., shape of the stimulus), subjective measures are mostly based on the phenomenological experience of the stimulus (Koster et al., 2020). The latter can lead to problems of validity if the applied rating scale asks rather unspecifically about "the stimulus" and not about the task-relevant feature (e.g., shape of the stimulus). Therefore, asking observers how clearly they perceived "the stimulus" instead of asking specifically how clearly "the shape of the stimulus"[41] was perceived can probably lead to different outcomes of assessments[42]. But how does this conform with the claim of several authors that subjective and objective measures can be equally sensitive, since they found that when participants report that subjective visibility is absent their performance in an objective discrimination task is also at chance (e.g., Avneon & Lamy, 2018; Lamy et al., 2015, 2017; Peremen & Lamy, 2014; Ramsøy & Overgaard, 2004)?

3.1.4. Criterion content

Visual perception differs from individual to individual. For this reason, one factor that is difficult to control in studies of visual awareness is the visual information that is actually used by the observer while performing the task. The crucial aspect here is which criterion will be used by an individual to map "his [or her] private [phenomenological] experience onto responses to the experimenter's questions" (Kahneman, 1968, p. 410). Kahneman (1967, see also 1968) as a pioneer of the term criterion content pointed out that labile phenomena such as metacontrast would critically depend on the observer's criterion.

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[40] As noted by Sandberg et al. (2010), "the rationale [of PDW] is that the wagers are based on the awareness of the participants …", and since observers do not have to "introspectively report their awareness" (p. 1071), PDW is sometimes treated as an objective direct measure (for instance by Persaud et al., 2007). Nonetheless, within this work PDW will be treated as a subjective measure of awareness.

[41] Likewise for other critical stimulus features such as "the color" or "the location" of the stimulus.

[42] See Section 4.4 "Double dissociations and criterion content" for a discussion on this issue.

Experimenters' efforts in the past to reduce the criterion problem, "by using highly experienced and knowledgeable observers" (Kahneman, 1967, p. 578) indeed would have improved reliability but would simultaneously suffer from the crippling defect of reproducibility.

As demonstrated by Albrecht and colleagues (e.g., Albrecht & Mattler, 2012, 2016; see also Koster et al., 2020), individual differences in metacontrast masking (type-A or type-B observers) result from individually different criterion contents, and the use of different *perceptual cues*. While type-A observers most often seem to use motion cues, such as a perceived change or rotational apparent movement in the stimulus sequence, type-B observers would most frequently report some kind of afterimage (Albrecht & Mattler, 2012, 2016).

Hence and most likely, individual response criteria will also differ between objective and subjective measures of visual awareness. Therefore, the question arises if different awareness measures can be equally sensitive. In a recent article by Koster et al. (2020), they suggest a multidimensional pattern of subjective experiences under metacontrast, which would have been reflected in dissociations between objective and subjective measures of visual awareness. According to the authors, these findings would challenge the use of simple one-dimensional measures (no matter whether subjective or objective) in visual masking; even more, expressing serious doubt that visual awareness can be assessed exhaustively by a single measure at all.

3.2 Experiment 1: Single versus triple task

Experiment 1 was conducted to study the time courses of priming and prime visibility under metacontrast masking in single and triple tasks. Two types of measures were employed for prime visibility: an objective measure of prime discrimination performance (response accuracy in %), and a subjective measure where the Perceptual Awareness Scale by Ramsøy & Overgaard (2004) was used for ratings on prime perception. In the triple task, participants first gave a speeded response to the shape of the mask (diamond or square with a central cut-out), then tried to discriminate the shape of the prime (diamond or square that fits into the cut-out) without time pressure, and finally performed the rating on the PAS. The same tasks were also performed as single tasks in separate sessions. To achieve comparable conditions for both single and triple tasks, the same stimuli, experimental processes (see Fig. 24), and participants were used for the respective task types. Performances under conditions of the triple task should be deteriorated relatively to the single task, because of a higher mental effort and cognitive control. Therefore, responses to the mask should be slower and prime discrimination as well as PAS ratings should be lower in the triple than in the single task. Since longer reaction times were suspected under conditions of the triple task, priming effects might no longer be carried by simple feedforward processing of the prime as proposed by Rapid-Chase Theory. For this reason, error response times in inconsistent trials were checked whether they were time-locked to the prime or to the mask. The most interesting question was whether a (double) dissociation between priming and prime visibility would be observable in any of the task types.

3.2.1 Methods

Participants. Eight right-handed volunteers, mainly students from the University of Kaiserslautern (4 male; mean age 29.1 years) took part in six 1-hour sessions.[43] Participant's vision was normal or corrected to normal. All of them were naïve to the purpose of the study and were recruited in the course of bachelor theses, which is why attendees did not receive payment or course credit. Each of them gave informed consent and was treated according to the ethical guidelines of the APA. After the final session, they were debriefed and received an explanation of the experiment.

Apparatus. The participants were seated in a dimly lit room in front of a color cathode-ray monitor (1280x1024 pixels, refresh rate 75 Hz) at a viewing distance of approximately 60 cm.

Stimuli and Procedure. Prime and mask stimuli were similar to those by Mattler (2003). At the beginning of each trial, a black fixation point appeared at the center of a white background (Fig. 24; ca. 63.0 cd/m). All stimuli were black squares or diamonds (0.04 cd/m²), differing in size and shape characteristics. Primes had an edge length of 1 cm (0.96° of visual angle) and appeared at fixation. Masks were squares or diamonds with an edge length of about 1.6 cm (1.53°) appearing at the same position as the primes. They had an additional central cut-out corresponding to the superposition of a square and a diamond

[43] All sessions were tried to be realized on separate days; however, in a few cases two sessions were performed on the same day with at least two hours between sessions.

prime, so that prime and mask shared adjacent but non-overlapping contours and both prime shapes could be masked by metacontrast (Breitmeyer & Öğmen, 2006).

The experiment consisted of three different tasks that were either performed within the same trial (triple-task conditions), or separately in different sessions (single-task conditions). Participants performed a speeded mask identification task (*mask ID* or *mID*), a non-speeded prime identification task (*prime ID* or *pID*), and a visibility rating on a four-point PAS. With the mask ID task, response priming was measured in consistent and inconsistent trials as an indirect measure of prime processing. The prime ID task is used as an objective measure of prime discriminability, while the PAS is designed to be a subjective measure of prime visibility. Both task types serve as direct measures of visual awareness of the prime.

Participants first performed one session of mask ID followed by one session of prime ID and finally one session of PAS ratings. Each session consisted of 31 blocks of 48 trials. Following this, participants performed three sessions in the triple-task condition, each consisting of 31 blocks of only 24 trials[44]. This sequence of tasks was chosen to give participants ample practice in the single tasks before taking on the more challenging triple task, and because the expected triple-task disadvantage should be estimated conservatively. The first block of each session was practice and not considered for further analysis. Stimulus sequences were identical in all sessions.

In the single-task condition, each trial started with a central fixation point, followed by a prime presented for 27 ms that was either of the same shape as the mask (consistent trial) or the other shape (inconsistent trial). Finally, the mask appeared after a prime-mask SOA of 27, 40, 53, or 67 ms, and remained on screen until the response. The time interval from fixation onset to mask onset was constant at 600 ms.

In the speeded *mask identification task*, participants responded to the shape of the mask as quickly and correctly as possible by pressing button ‘F’ on the computer keyboard upon seeing a diamond or button ‘J’ upon seeing a square (or vice versa; the assignment was counterbalanced across participants). They used the two index fingers to respond and directly received visual feedback if the response was incorrect or too slow (> 1,000 ms).

In the *prime identification task*, participants identified the shape of the prime without time pressure and without trial-to-trial feedback using the same stimulus-response mapping as in the mask ID task. After each block, participants could take a break and

[44] Session durations between the task conditions should be kept similar.

received summary feedback (on mean reaction time, mean accuracy, and number of errors in the mask ID, but only on mean accuracy in the prime ID).

In the *perceptual awareness rating*, participants rated their visual impression of the prime on a four-point rating scale (PAS) by pressing the digit keys from 1 to 4. The specifications of the rating scale were visually presented on screen. The scale categories were *"1: kein Erlebnis" (no experience)*, *"2: flüchtiger Eindruck" (brief glimpse)*, *"3: nahezu klares Erlebnis" (almost clear experience)*, and *"4: klares Erlebnis" (clear experience)"*. Additionally, participants had a brief description of the rating categories on the instruction sheet (Table 1; German translation of the original PAS, Ramsøy & Overgaard, 2004). All combinations of prime shape, prime-mask consistency, and SOA were presented equiprobably and pseudo-randomly in each block.

Table 1: Categories and descriptions of the Perceptual Awareness Scale. *Left*: The original by Ramsøy and Overgaard, 2004; *right*: German translation.

Perceptual Awareness Scale

Ramsøy & Overgaard, 2004		German translation	
Category	Description	Kategorie	Beschreibung
No experience	No impression of the stimulus. All answers are seen as mere guesses.	1 = “kein Erlebnis” (no experience)	Kein Eindruck des Stimulus. Meine abgegebene Antwort ist geraten.
Brief glimpse	A feeling that something has been shown. Not characterized by any content, and this cannot be specified any further.	2 = “flüchtiger Eindruck” (brief glimpse)	Ich hatte das Gefühl, dass irgendetwas gezeigt wurde, kann aber keine deutliche Unterscheidung treffen.
Almost clear experience	Ambiguous experience of the stimulus. Some stimulus aspects are experienced more vividly than others. A feeling of almost being certain about one’s answer.	3 = “nahezu klares Erlebnis” (almost clear experience)	Zweideutige Wahrnehmung des Stimulus. Einige Stimuluseigenschaften wurden klarer wahrgenommen als andere. Ich habe beinahe das Gefühl, den Stimulus erkannt zu haben.
Clear experience	Non-ambiguous experience of the stimulus. No doubt in one’s answer.	4 = “klares Erlebnis” (clear experience)	Kein zweideutiges Erlebnis des Stimulus, kein Zweifel bei der gegebenen Antwort.

Under triple-task conditions, participants performed exactly the same three tasks, but this time within the same trial. Therefore, participants first responded to the mask as quickly and accurately as possible, then tried to identify the prime (always using the same stimulus-response mapping), and finally rated their visual impression of the prime on the PAS. Timing was changed according to the requirement that now three responses instead of one had to be given within a trial sequence. Therefore, the time interval from fixation to mask-onset was 1600 instead of 600 ms. The mask stimulus remained on screen until the final response. Visual feedback was given after the final response. To make the task easier, a visual instruction was presented at the time of prime identification, saying, “Identify the prime!” Participants received summary feedback after each block as described before.

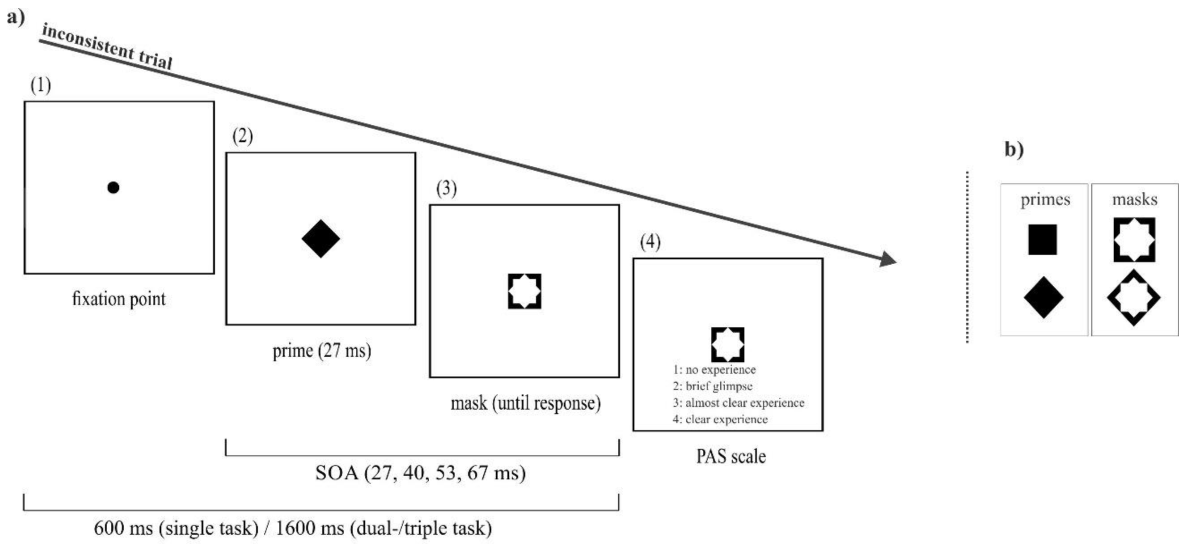

Figure 24 a) Stimuli and trial sequence in all experiments. Mask stayed on screen until the final response to either the mask identification task (mask ID, e.g., dual task setting), or the visibility rating of the PAS (triple task setting) was given by the participant. The PAS display was only shown in the triple task and the respective single task of Experiment 1. **b)** Prime and mask stimuli used in all experiments.

Data treatment and statistical methods. Dependent variables were response time and error rate in the mask identification task, response accuracy in the prime identification task, and the PAS ratings. Practice blocks were not analyzed. Reaction times were summarized by trimmed means; error trials were not included in response time analysis. In the mask identification task, response times shorter than 100 ms or longer than 1199 ms were eliminated as outliers (0.10 % in single task; 0.94 % in triple task).[45] For averaged data, repeated-measures analysis of variance (ANOVA) was performed with factors of consistency (*C*), SOA (*S*), and task type (*T*). Error rates and response accuracy were arcsine-transformed to meet ANOVA requirements. For clarity, all results are reported with Huynh-Feldt-corrected *p* values but the original degrees of freedom, and effects are specified by subscripts to the *F*-values (e.g., F_{CxS} for the interaction of consistency and SOA). While these models are designed to generalize to new participants, data was also analyzed within each participant. For response times and PAS ratings, this was done by ANOVA of individual trials; for accuracy data and error rates, the ANOVA was realized via SPSS's logistic regression module. Note that those models generalize to further trials from a given participant. All ANOVA effects significant at $p \leq .05$ will be reported, so that unreported effects are always nonsignificant, with the understanding that *p* values between .01 and .05 should be regarded with caution. Additionally, I may mention *p* values between .05 and .10 if important to the argument.

In multi-factor repeated-measures designs, statistical power can be calculated if all effect sizes can be predicted along with their respective error variances. In practice, however, too many terms are unknown for a meaningful power analysis. Because the number of trials per participant and condition is about as important for power as the number of participants (Arend & Schäfer, 2019; Smith & Little, 2018), measurement precision is controlled at the level of individual participants in single tasks and stimulus conditions. For each task, precision was calculated as $s/\sqrt{r}$ (Eisenhart, 1963), where *s* is a single participant's standard deviation in a given cell of the 2x4-design (Consistency x SOA) and *r* is the number of repeated measures in each cell and subject. With $r = 180$ and 270 in the single and triple task conditions, respectively, a precision of about 4.5 ms and 3.7 ms was expected in response times (assuming individual SDs around 60 ms), and at most 3.7 and 3.0 percentage points in accuracy scores (assuming the theoretical maximum SD of .5). Precision thus exceeds previous recommendations for response priming studies ($r = 60$, F. Schmidt et al., 2011).

[45] In experiments on response priming, our research group would usually use an upper cutoff value of 999 ms, which would lie in the far-right tail of the response time distribution. The criterion was adjusted to 1199 ms based on visual inspection of the response time histogram to cut a similar proportion as usual.

3.2.2 Results and Conclusion

Response times and error rates in mask identification

In the mask ID task, response priming effects were expected in response times and error rates. Because response priming is generated by a response conflict that is aggravated when the prime has more time to impact the response, priming effects in both measures should increase with prime-mask SOA, with response errors predominantly occurring in inconsistent trials at long SOAs (Panis & Schmidt, 2016; F. Schmidt et al., 2011; Vorberg et al., 2003). Due to the assumption that triple tasks might cause higher cognitive load and divided attention, longer response times, smaller priming effects, and more errors under triple-task conditions compared to the single task were expected.

The following figure (Fig. 25) shows response times and error rates in individual participants and the results of within-subject ANOVAs[46]. In single tasks, most participants show regular response priming effects (faster responses in consistent than in inconsistent trials) that tend to increase with SOA. Priming effects also occur in the triple task, but response times are extremely delayed (in Participant 5, by about 300 ms) and clearly increase with SOA in only one participant (2). In some participants, priming effects are larger in the triple than in the single task. Four participants show very large priming effects at the shortest SOA (Participants 2, 3, 6, and 7), and for Participants 3 and 6 this SOA even yields the largest priming effects.

[46] See Appendix A for test statistics and *p* values.

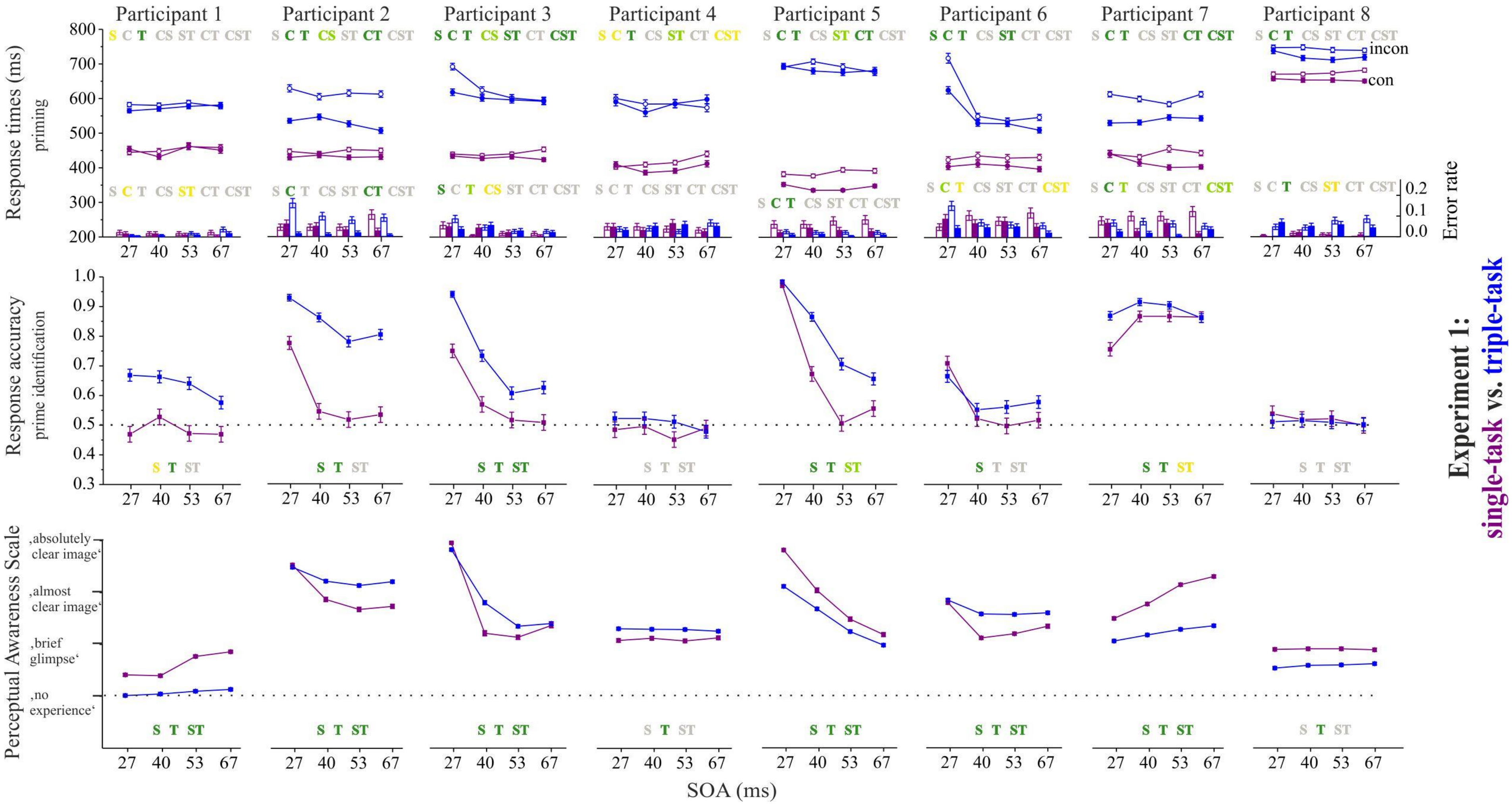

Figure 25. Experiment 1. Individual results of the mask identification task (upper row, response times and error rates), the prime identification task (middle row, response accuracies), and of perceptual awareness ratings (bottom row, perceptual awareness scale) in all eight participants. Letters denote main effects and interactions in within-participant ANOVAs. Factors are coded S (SOA), C (Consistency), and T (Task). Grey: $p > .05$; yellow: $p < .05$; light green: $p < .01$; dark green: $p < .001$.

Despite those differences between participants, the averaged data provide a clear pattern of effects (Fig. 26). ANOVA with factors of consistency (*C*), SOA (*S*), and task type (*T*) showed that responses were slower (by a massive 162 ms) in the triple task than in the single task, F_T (1, 7) = 37.57, p < .001. Overall, responses were faster for consistent than for inconsistent trials, F_C (1, 7) = 21.12, p = .002. As expected, this priming effect increased over SOA for single tasks, but surprisingly decreased with SOA in the triple task (Fig. 27, center), resulting in a three-way interaction, F_{TxCxS} (3, 21) = 5.97, p = .004. Separate ANOVAs for the two task types confirmed significant priming effects in both single and triple tasks, F_C (1, 7) = 23.45 and 9.20, p = .002 and .019, respectively, and an increase in priming with SOA for single tasks, F_{CxS} (3, 21) = 6.34, p = .003. The decrease in priming in the triple task, which is mostly due to Participants 3 and 6 at the shortest SOA, was not significant.

The analogous analysis of the error rates revealed significant priming effects for single as well as triple tasks. Error rates were higher in inconsistent than in consistent trials, F_C (1, 7) = 6.93, p = .034, and this priming effect increased with SOA, F_{CxS} (3, 21) = 3.81, p = .025. Analyses performed separately for the two task types revealed a main effect of consistency that was significant in the triple task, F_C(1, 7) = 6.14, p = .042, but not in the single task, F_C(1, 7) = 3.69, p = .096. An interaction with SOA was only observable in the single task, F_{CxS} (3, 21) = 3.90, p = .026. Generally, the pattern of errors was in agreement with the pattern of response times.

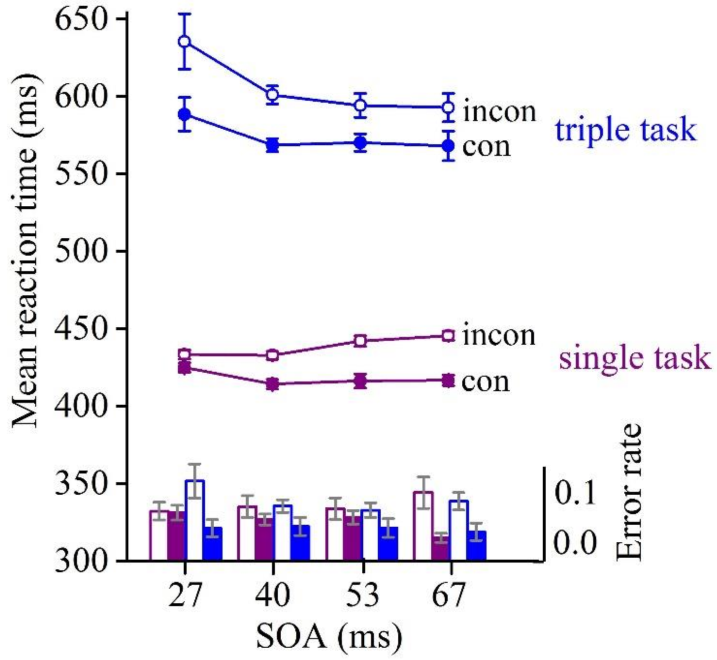

Figure 26. Experiment 1. Averaged reaction times in milliseconds and error rates in the mask ID task for both types of tasks (single versus triple task), and consistencies (consistent versus inconsistent). Here and in all further plots where participants are averaged, standard errors of the mean are corrected for intersubject variance (Cousineau, 2005). The correction was performed separately for single and triple tasks.

Check for fast errors

Rapid-Chase Theory predicts fast errors in inconsistent trials because those responses are produced by feedforward processing of the inconsistent prime. Therefore, incorrect responses to the mask should be as fast as the fastest correct responses. This was checked by applying an ANOVA model to the trimmed responses, treating response accuracy and SOA as fixed factors, and including participants as a random factor to control for repeated measures. Because of the low and unbalanced error rates, this test had to be carried out on the level of single trials, drawn from all participants. This model was applied to the inconsistent trials in single and triple tasks. Because this analysis uses a dependent variable as a factor it is quite unbalanced, but the main effects of response accuracy were of primary interest. For inconsistent trials in single tasks, error responses were 85 ms faster than correct responses $F(1, 27.76) = 120.74$, $p < .001$, while in the triple task the difference was less than 2 ms, $F(1, 9.82) = 0.02$, $p = .903$. Task types also differed in whether the error response times in inconsistent trials were time-locked to the prime or to the mask, which can be tested by regressing mask-locked and prime-locked response times to the prime-mask SOA. These two slopes would be -1 and 0 if errors were perfectly time-locked to the prime, and 0 and 1 if errors were perfectly time-locked to the mask. In the single task, the slopes were -0.71 (p = .021) and 0.29 (p = .337), which indicates that responses are (imperfectly) locked to the prime rather than the mask. In the triple task, however, the slopes were -1.95 (p < .001) and -0.95 (p = .040), which are inconsistent with both prime-locking and mask-locking.

Accuracy in prime discrimination and PAS ratings

For an objective measure of prime discriminability, the percentage of correct responses to the prime (Fig. 27, left) was used. Under complete masking, prime discriminability should be at chance level (50 %).

As described, participants differed markedly in their masking functions (see Fig. 25). Except for Participants 4 and 8, all participants performed significantly better in the prime identification task under the triple-task condition, contrary to the expectation that under these conditions performances will be impaired. This is illustrated best in Participant 1, who performed at chance under single-task conditions but reached an accuracy of 63.7 % in the context of the triple task. This finding was a surprise because prime ID performance was expected to be impaired under the triple-task condition due to higher cognitive load and divided attention. The performance advantage in the triple-task condition is most likely an effect of training, because the triple-task condition was always performed after the single-task conditions. This procedure has been used because it was expected that the challenging triple-task condition would benefit from single-task training, so that the hypothesis of a triple-task disadvantage could be tested conservatively. When performance is traced over sessions, most participants show a smooth learning curve in prime discrimination performance across the single-task session and the subsequent triple-task sessions, consistent with a gradual effect of training.

Otherwise, the participants' individual data patterns differ strongly and even qualitatively. Four participants (2, 3, 5, and 6) show type-B masking, with discrimination performance decreasing with SOA, sometimes strongly. Two more participants (4 and 8) perform at chance level throughout; both show clear evidence of response priming. In contrast, Participant 7 consistently performs around 80 to 90 % accuracy. Finally, Participant 1 performs at chance in the single task but around 65 % correct in the triple task. Because of these qualitative differences between observers, it is not advisable to rely (only) on the averaged data from the usual omnibus analysis of variance. This could be highly misleading.

Nevertheless, averaged across participants, ANOVA showed a significant main effect of task type, F_T (1, 7) = 9.91, p = .016, and a less reliable main effect of SOA, F_S (3, 21) = 4.82, p = .056 (Fig. 27, left). No interaction of these two factors was found, F_{TxS} (3, 21) = 1.22, p = .326. Simple tests showed that the SOA effect was significant in the triple task but not in the single task, F_S (3, 21) = 5.34 and 3.81, p = .033 and .088, respectively. Note that no single participant's response pattern (Fig. 25) closely resembled this average pattern.

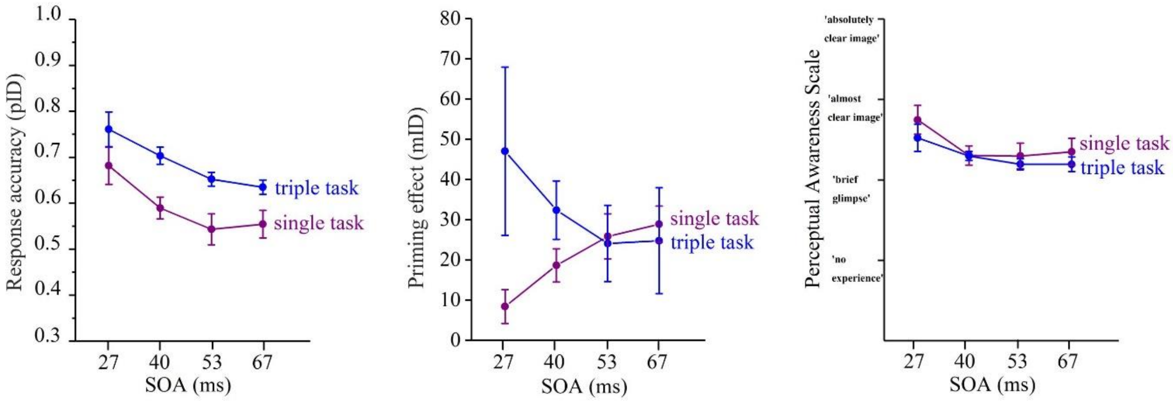

Figure 27. Experiment 1. *Left:* Average response accuracy (percentage of correct responses) in the prime identification task, plotted for single (purple) and triple task (blue), respectively. *Center:* Average response-time priming effects ($RT_{incon} - RT_{con}$) in the mask identification task. *Right:* Average ratings on the Perceptual Awareness Scale.

Another surprise was that prime discrimination accuracy is often dissociated from the PAS ratings. For example, Participant 8 gives higher PAS ratings in the single than in the triple task, yet his or her discrimination accuracy is at chance in both cases. Participants 4 and 8 both perform objectively at chance but consistently give PAS ratings indicating a "brief glimpse". In Participants 1, 5, and 7, prime discrimination is more accurate in the triple than in the single task, but PAS ratings are lower. This indicates that both tasks do not measure awareness in the same way, or more explicitly, that each of them provides different kinds of information. Again, the qualitative differences between individual PAS functions make it inadvisable to draw conclusions from averaged data only, since ANOVA showed no significant effects at all (Fig. 27, right), neither a difference between single and triple task, F_T (1, 7) = 0.72, p = .424, nor a main effect of SOA, F_S (3, 21) = 2.09, p = .184, nor an interaction, F_{TxS} (3, 21) = 1.80, p = .200. This apparent null result would be highly misleading: it belies the fact that individual PAS functions were highly reliable but differed qualitatively across observers (see Fig. 25).

Conclusion

Experiment 1 shows that the change from single-task to triple-task conditions has dramatic consequences for the pattern of dissociations between direct and indirect tasks. When prime identification performance was measured in single tasks, participants scored either near chance or showed a type-B masking function that decreased with SOA. At the same time, these participants show increasing priming effects and thus opposite effects of SOA on priming and masking (double dissociation, Mattler, 2003; Vorberg et al., 2003). In sum, double dissociation patterns were observable in four of the eight participants, simple dissociations in two participants, and no dissociations in another two.

If the same measures are obtained under triple-task conditions, the pattern of results changes. First, there are large main effects: responses are 162 ms slower than under single-task conditions, and prime ID performance is markedly higher. The smooth learning curve in prime ID performance across the single-task session and the subsequent triple-task sessions suggests that participants tried to optimize this performance to the detriment of the mask identification task, which suffers greatly from the increase in cognitive load and divided attention. Second, all double dissociations between priming effects and prime ID performance are lost: on average, priming effects now *decrease* with SOA together with prime identification accuracies, and this is the case also in individual participants (even though this average decrease is due to only two participants). While this loss of dissociation is in line with Peremen and Lamy's (2014) findings, it is still questionable that it reveals an artifact created by the single-task measurement. More likely, it is a disruption of the response activation process by the triple task. It seems that the triple task slows responses to the mask so much that the effects are no longer based on simple feedforward processing; it may instead occur out of a memory representation and even be subject to response inhibition. The absence of the characteristic early and rapid errors from the triple-task condition and the absence of time-locking of errors to the onset of the prime is another indicator that the prime has lost the power to drive motor responses to completion.

Finally, the patterns of prime ID performance and PAS ratings are inconsistent. On average, prime ID performance decreases with SOA and is higher in the triple task, while PAS ratings are invariant across all those conditions. Upon closer analysis, however, it is evident that some participants show higher PAS ratings in the triple task while others show lower ones, and that ratings can increase, decrease, or stay invariant across SOAs in individual observers. In addition, participants who perform at chance in the objective task do not give zero ratings in the subjective task. Because neither the PAS ratings nor the prime ID accuracies are particularly noisy, it can be assumed that the two tasks capture different stimulus aspects and thus differ in criterion content (Kahneman, 1968).

3.3 Experiment 2: Single versus dual task

In the first experiment, speeded mask ID, unspeeded prime ID, and PAS ratings under single- and triple-task conditions were compared. The findings demonstrated that the triple task condition did not impair prime ID performance, which steadily increased across sessions, but greatly impaired response priming effects, resulting in strongly delayed responses, decreasing instead of increasing priming effects, and a loss of fast prime-locked errors in inconsistent trials. Whereas both single and double dissociations were observed under single-task conditions, most of these dissociations were lost in the triple task. In Experiment 2, it was investigated whether similar impairments arise under dual-task conditions where only response priming and prime discrimination are measured on the same trial.

3.3.1 Methods

Participants. Eight volunteers, mostly students from the University of Kaiserslautern (4 male; age range 22-25 years) took part in four 1-hour sessions. None of them had participated in Experiment 1, and all of them were naïve to the purpose of the study. Participants were recruited in the course of bachelor theses, which is why attendees did not receive payment or course credit. Their vision was normal or corrected to normal. Each of the participants gave informed consent and was treated according to the ethical guidelines of the APA. All of them were debriefed and received an explanation of the experiment after the final session.

Apparatus, stimuli and procedure. The equipment, stimuli and procedures were the same as in Experiment 1 (see Fig. 24), but with the exception that participants performed only two tasks (mask ID, prime ID) within the same trial (dual-task condition), or in different sessions (single-task condition). This time, no subjective awareness rating was implemented.

All participants performed 31 blocks of 48 trials in the single-task condition and of 36 trials in the dual-task condition to obtain session times of equal duration. Due to a programming mistake, the final block stopped after 28 trials in the dual task. For both conditions, the first block was always a practice block. Each participant performed one session of mask ID, followed by one session of prime ID, followed by two sessions of the dual task. All stimulus combinations were presented equiprobably and pseudo-randomly in each block.

Data treatment and statistical methods. Data treatment proceeded as in Experiment 1. In the mask ID task, 0.05 and 0.16 % of trials were discarded as outliers in the single and dual task, respectively. Repeated-measures analysis of variance (ANOVA) was performed with factors of consistency (*C*), SOA (*S*), and task-type (*T*) on response times and arcsine-transformed error rates. Measurement precision ($s/\sqrt{r}$, with $r = 180$ and 270 in the single and double task conditions) was the same as in Experiment 1.

3.3.2 Results and Conclusion

Response times and error rates in mask identification

Individual patterns of response times and error rates of the participants and the results of within-subject ANOVAs[47] are shown in the following figure (Fig. 28). In single tasks, most participants show regular response priming effects (faster responses in consistent than in inconsistent trials) that tend to increase with SOA. Response times in the dual task are strongly delayed, but not nearly as much as in the triple task of Experiment 1. Priming effects are generally larger in the dual than in the single task; importantly, they generally increase with SOA (except for Participant 5, who shows the largest priming effect at the shortest SOA).

[47] See Appendix B for test statistics and *p* values.

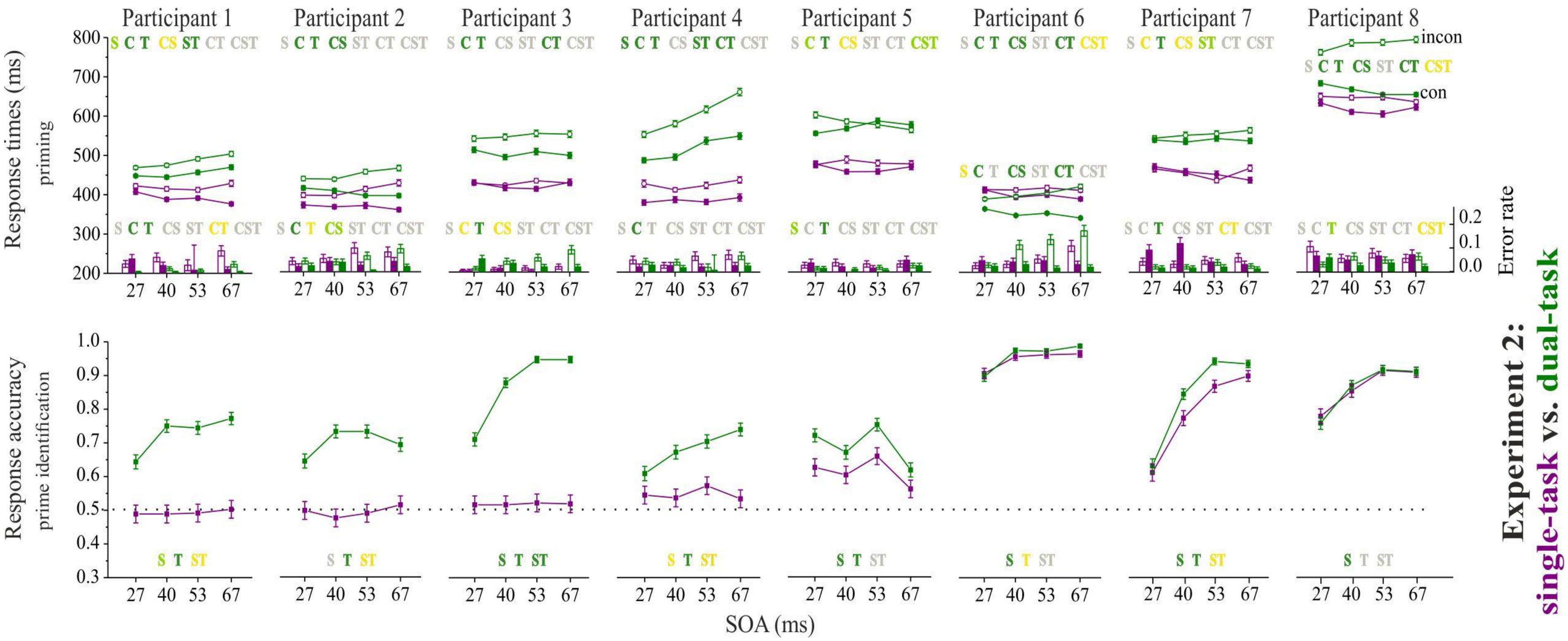

Figure 28. Experiment 2. Individual results of the mask identification task (upper row, response times and error rates) and the prime identification task (lower row, response accuracies) in all eight participants. Conventions are the same as in Figure 25.

Even though participants differ markedly in the magnitude of their priming effects, the average data provides a clear pattern of effects. Responses were faster for consistent than for inconsistent trials, F_C (1, 7) = 21.87, p = .002, and this priming effect increased over SOA, F_{CxS} (3, 21) = 4.57, p = .020. Response times were on average 76 ms faster in the single than in the dual-task condition, F_T (1, 7) = 15.84, p = .005, while priming effects were larger in the dual task, F_{TxC} (1, 7) = 7.10, p = .032. ANOVAs performed separately for single and dual tasks revealed significant main effects of consistency, F_C(1, 7) = 16.94 and 17.20, both p = .004, and a significant main effect of SOA for the single task, F_S(3, 21) = 3.91, p =.043, but no significant interaction effects in either task (Fig. 29).

An analogous ANOVA was also performed for the arcsine-transformed error rates, showing that more errors occurred in inconsistent trials, F_C (1, 7) = 11.96, p = .011, and that this priming effect increased with SOA, F_{CxS} (3, 21) = 10.70, p < .001. Overall, error rate tended to increase with SOA, F_S (3, 21) = 3.14, but not significantly, p = .054. The remaining effects were nonsignificant. ANOVAs performed separately for single and dual tasks revealed a significant main effect of consistency only for the dual task, F_C(1, 7) = 12.20, p = .010, but not for the single task, F_C(1, 7) = 4.30, p = .077. Priming effects increased with SOA both in the single task, F_{CxS}(3, 21) = 4.28, p = .021, and in the dual task, F_{CxS}(3, 21) = 9.29, p = .001. Error rates increased with SOA in the dual task only, F_S(3, 21) = 4.06, p = .020.

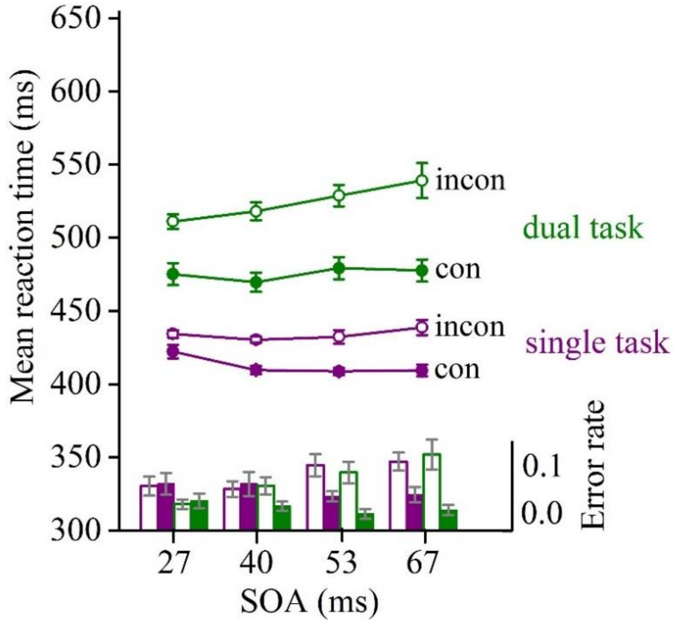

Figure 29. Experiment 2. Mean reaction times and error rates in the mask ID task for the two task types, and consistencies.

Check for fast errors

Fast errors in inconsistent conditions were checked by applying the same ANOVA models as in Experiment 1 to single and dual tasks. For single tasks, error responses in inconsistent trials were 62 ms faster than correct responses, $F(1, 8.12) = 27.21$, $p = .001$, while in the dual task they were only 20 ms faster, $F(1, 8.76) = 2.78$, $p = .131$. These inconsistent error trials were also checked for time-locking, using the same regression technique as in Experiment 1. When regressing mask-locked and prime-locked response times to the SOA, the two slopes would be -1 and 0 if errors were perfectly time-locked to the prime, and 0 and 1 if errors were perfectly time-locked to the mask. The slopes were -1.10 ($p = .007$) and -0.10 ($p = .813$) in the single task, and -1.06 ($p = .049$) and -0.06 ($p = .912$) in the dual task, indicating near-perfect time-locking to the prime in both task types.

Accuracy in prime identification

Again, participants differed markedly in their masking functions (Fig. 28). Under single-task conditions, Participants 1, 2, 3, and 4 basically performed at chance level at all SOAs when trying to identify the prime but showed huge increases in performance in the dual task. In the remaining participants, dual-task gains are much smaller (Participants 5 and 7) or absent (Participants 6 and 8). Except for Participant 6, all participants performed the mask ID task slower in the dual task than in the single task; in some participants, these dual-task losses were massive. This data pattern is in line with the findings of Experiment 1. Nevertheless, in Participants 3, 4, and 8, priming effects are larger in the dual task. In Participants 3 and 4, this increase in the priming effect coincides with an increase in prime ID accuracy, but in Participant 8, it does not. There is no indication that priming effects might decrease under dual-task conditions (with the possible exception of Participant 5).

Within Experiment 2, this new group of observers generally showed type-A masking functions; but nonetheless, because of the qualitative differences between observers, it is not advisable to average them to perform the usual omnibus analysis of variance. Nevertheless, averaged across participants, ANOVA showed a significant main effect of task type, $F_T\,(1, 7) = 9.91$, $p = .016$, a main effect of SOA, $F_S\,(3, 21) = 5.89$, $p = .036$, and a significant interaction indicating that the increase with SOA was steeper in the dual than in the single task, $F_{TxS}\,(3, 21) = 3.81$, $p = .028$. Simple tests showed that the

SOA effect was significant in the dual task but not in the single task, $F_S\,(3, 21) = 7.25$ and 2.40, $p = .031$ and .156, respectively. As in Experiment 1, no single participant's response pattern (see Fig. 28) closely resembled this average pattern.

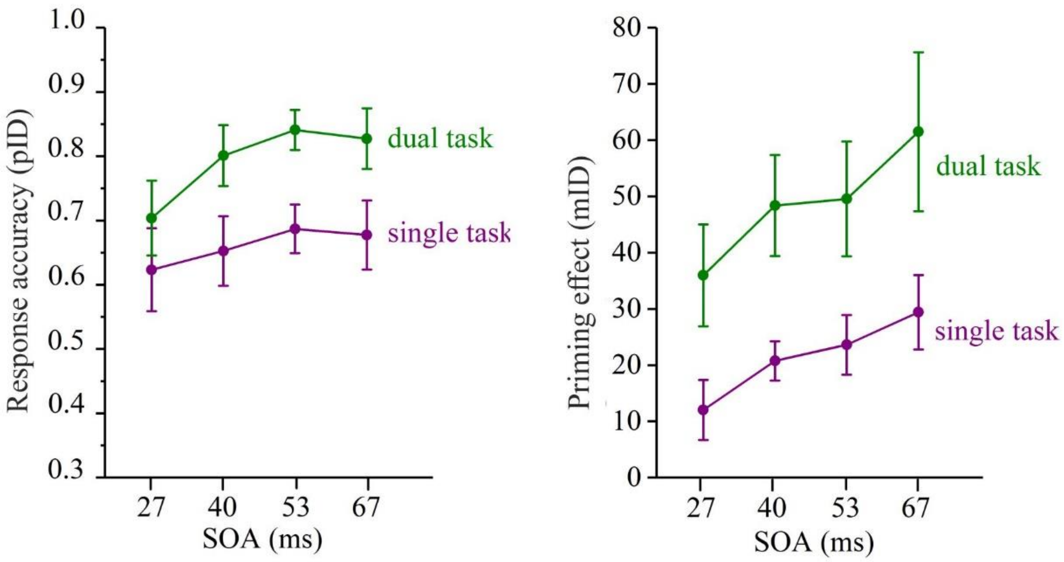

Figure 30. Experiment 2. *Left:* Average response accuracy in the prime identification task. *Right:* Average response-time priming effects in the mask identification task.

Conclusion

When prime identification performance and priming effects were each measured in a single task, priming effects increased with SOA while prime ID performance also showed a slight (nonsignificant) increase. Individual participants scored either near chance level or showed a type-A masking function that increased with SOA. At the same time, most participants show increasing priming effects. Unfortunately, none of them showed type-B masking, making it impossible to assess whether any double dissociation (increasing priming effects under decreasing prime discrimination performance) can be observed under dual task conditions. It should be noted that prime discrimination performance is still not able to predict the magnitude of priming. For example, of the two participants showing only little priming, one performed near chance level in prime ID (Participant 3) while the other one was almost perfect (Participant 6). Similarly, there are two participants (6, 8) in which masking functions are virtually identical under both task conditions, while the priming effects are strongly different.

As in Experiment 1, there are systematic changes in the pattern of results when the same measures are obtained under dual-task conditions. Again, accuracy in prime ID is much higher than under single-task conditions and responses are much slower (even though not as slow as in the triple task of Experiment 1) and show larger priming effects. Second, the simple dissociations between priming effects and prime ID performance are lost: those participants who scored at chance in prime ID now score much higher (e.g., Participant 3 improves from chance level to more than 90 % accuracy).

Perhaps most importantly, the structure of the response priming effects seems altered under dual-task conditions: whereas errors provoked by inconsistent primes are usually fast in single tasks, the dual task not only leads to slower correct responses but also to slower errors, such that the speed difference between correct and incorrect responses is no longer significant. On the other hand, error responses remain time-locked to prime onset. According to Rapid-Chase Theory, fast errors occur in inconsistent trials due to the feedforward response activation from the inconsistent prime. As conclusion and even though the dual-task situation seems less disruptive for response priming than the triple-task situation, pure feedforward processes are harder to guarantee under dual tasks than under single tasks.

3.4 Experiment 3: *Alternating* single and dual tasks sessions

In both Experiments 1 and 2, participants showed better performance in prime discrimination in multitasks than in single tasks. The level of performance in the prime ID increased rather steadily across all blocks and sessions – in most participants, it formed a relatively smooth power function (however, there was a little up-step in performance between single- and dual-task sessions in Experiment 2). This multitask advantage was most likely caused by the decision to perform the multitask sessions after the single-task sessions to give the multitasks the benefit of optimal practice. Under conditions of the dual and triple task, it was assumed that prime discrimination would be more difficult due to the situation that observers would be forced to divide their attention across stimuli and features. Thus, multiple tasks should benefit from the additional training to avoid an underestimation of their sensitivity.

To clarify this issue, in Experiment 3 single- and dual-task sessions were alternated to guarantee comparable practice for both task types.

3.4.1 Methods

Participants. Eight volunteering students from the University of Kaiserslautern (4 male; age range 19-31 years) took part in four 1-hour sessions for payment. None of them participated in Experiment 1 or 2. Their vision was normal or corrected to normal. All of the participants were naïve to the purpose of the study. Each of the participants gave informed consent and was treated according to the ethical guidelines of the APA. All of them were debriefed and received an explanation of the experiment after the final session.

Apparatus, stimuli and procedure. The apparatus, equipment and stimuli were the same as in Experiments 1 and 2 (see Fig. 24). In contrast to the procedure of Experiment 2, both single and dual tasks were performed in alternating task sessions. Unfortunately, the data set of one participant had to be deleted because the key assignment was mistakenly changed between two sessions. Therefore, the data of a newly recruited participant replaced the missing data set, achieving a balanced number of male and female participants. In each task, all participants performed 31 blocks of 48 trials under single-task conditions, and 31 blocks of 32 trials in the dual task. For both conditions, the first block was always a practice block.

Data treatment and statistical methods. Data treatment proceeded as in Experiments 1 and 2. In the mask ID task, 0.05 and 0.24 % of trials were discarded as outliers in the single and dual task, respectively. Repeated-measures analysis of variance (ANOVA) was performed with factors of consistency (C), SOA (S), and task-type (T) on response times and arcsine-transformed error rates. Measurement precision ($s/\sqrt{r}$, with $r = 180$ and 270 in the single- and dual- task conditions) was the same as in Experiments 1 and 2.

3.4.2 Results and Conclusion

Response times and error rates in mask identification

Response times and error rates in individual participants and the results of the within-subject ANOVAs[48] are shown in Figure 31. In both single and dual task, participants show response priming effects, which most importantly increase over SOA for most of the observers, although they are relatively small. Again, response times under the

[48] See Appendix C for test statistics and p values.

dual task are delayed (in Participants 2, 6, and 8 by almost about 150 ms), while Participant 2 generally performs at a higher level for both task types compared to the rest. While for Participants 7 the characteristically increasing priming pattern can be observed for both task conditions, Participant 4 performs almost constant for both consistencies and task types, respectively.

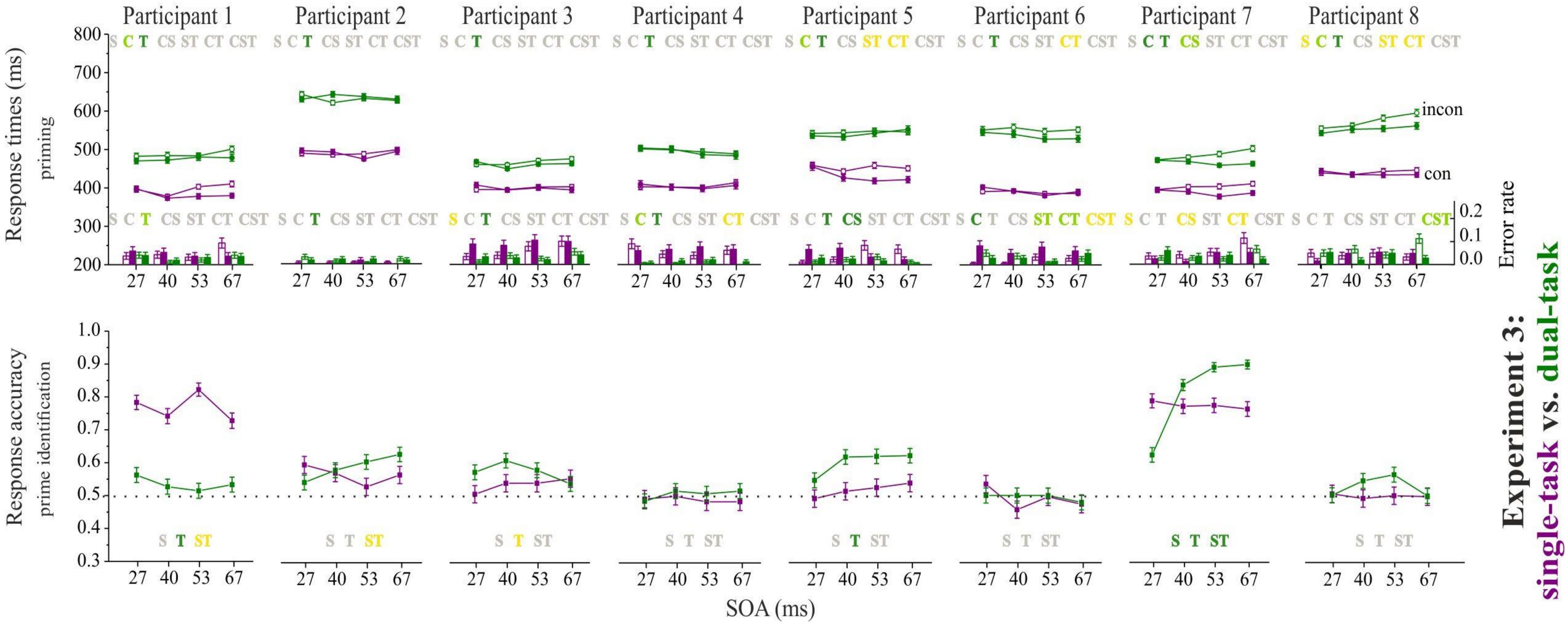

Figure 31. Experiment 3. Individual results of the mask identification task (upper row, response times and error rates) and the prime identification task (lower row, response accuracies) in all eight participants. Conventions are the same as in Figure 25.

Despite these individual differences, the average data provide a similar pattern of effects for both task types (Fig. 32). ANOVA with factors of consistency (*C*), SOA (*S*), and task type (*T*) showed that responses were faster for consistent than for inconsistent trials, F_C (1, 7) = 11.57, p < .001, and this priming effect increased over SOA F_{CxS} (3, 21) = 11.08, p < .001 (see Fig. 33, right). As expected, responses for single and dual tasks differed greatly with respect to their mean reaction times. Response times were on average 106 ms faster in the single- than in the dual-task condition, F_T (1, 7) = 93.34, p < .001. ANOVA performed separately for the single task revealed a significant main effect of SOA, F_S (3, 21) = 5.00, p = .009, and an interaction of consistency and SOA, F_{CxS}(3, 21) = 23.74, p < .001. A separate analysis of the dual task only revealed a main effect of consistency, F_C (1, 7) = 9.04, p = .020.

The individual analysis of error rates only exhibited a main effect of SOA for the single task, F_S (3, 21) = 3.89, p = .023.

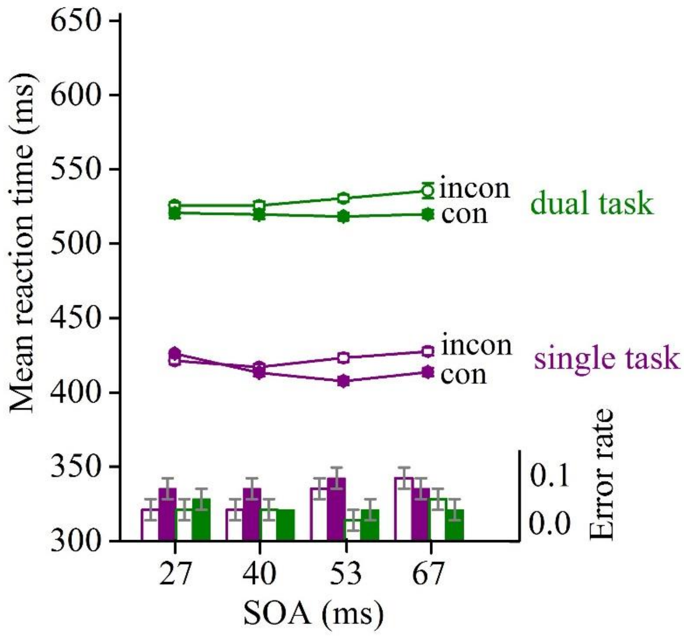

Figure 32. Experiment 3. Mean reaction times and error rates in the mask ID task for the two task types, and consistencies.

Check for fast errors

The same ANOVA model and regression technique as in Experiments 1 and 2 were applied to single and dual tasks of Experiment 3. For single tasks, error responses in inconsistent trials were 60 ms faster than correct responses, F (1, 13.58) = 20.31, p = .001, while in the dual task they were slower by nonsignificant 13 ms, F (1, 10.81) = 0.45, *p* = .519. When regressing mask-locked and prime-locked response times to the SOA, the two slopes would be -1 and 0 if errors were perfectly time-locked to the prime, and 0 and 1 if errors were perfectly time-locked to the mask. The slopes were -0.37 (p = .247) and 0.635 (p = .045) in the single task, and -0.768 (p = .373) and 0.232 (p = .787) in the dual task, which indicates no clear time locking to either stimulus in either task.

Accuracy in prime identification

In Experiment 3, single- and dual tasks were alternated to guarantee an optimal practice for both task types. If the assumption would be correct that the multitask benefit of Experiments 1 and 2 was a result of differential training due to non-alternating task sessions, prime discrimination performance in Experiment 3 should be more comparable between the task types. Indeed, for most observers, prime discrimination performance was similar in single and dual task, supporting the assumption of differential training (see Fig. 31). With Participants 4, 6, and 8 performing at chance level and Participants 2, 3 and 5 ranging between a level of 50 % and 60 % correct responses, only two participants show surprising data patterns. Participant 1 performs much better in the single than in the dual task and in Participant 7 a single-task advantage at the shortest SOA turns into a dual-task advantage as soon as performance in dual task increases with SOA. Across participants (Fig. 33, left), however, there is no longer a consistent pattern of better performance in the dual task as it was observable under non-alternating dual-task conditions of Experiment 2.

While in Experiment 2 most observers performed qualitatively better under conditions of the dual task compared to the single task, in Experiment 3 there are significantly fewer differences in the performance level within the same observer and task type. Nevertheless, for most of the participants (except for Participant 1 who showed a large effect in the opposite direction of the masking function), masking functions under dual-task conditions still exhibit slightly better performances, albeit generally showing type-A masking (see Fig. 31). Maybe observers can harvest additional information (e.g., notice signs of the response conflict in the response to the mask, using this information to guess the prime) about the prime in the dual task, which could be helpful to increase performance. Due to the increased difficulty (more information must be stored in working memory) compared to the simple task, observers may use such strategies more often.

The average data provide a similar pattern of effects, where prime identification performance was constant (about 58 % correct) across SOAs and similar under single and dual-task conditions, with no main effects of SOA (p = .284) or task type (p = .975) and no interaction (p = .168). Separate analyses for single and dual tasks revealed no SOA effects either, p = .591 and .191.

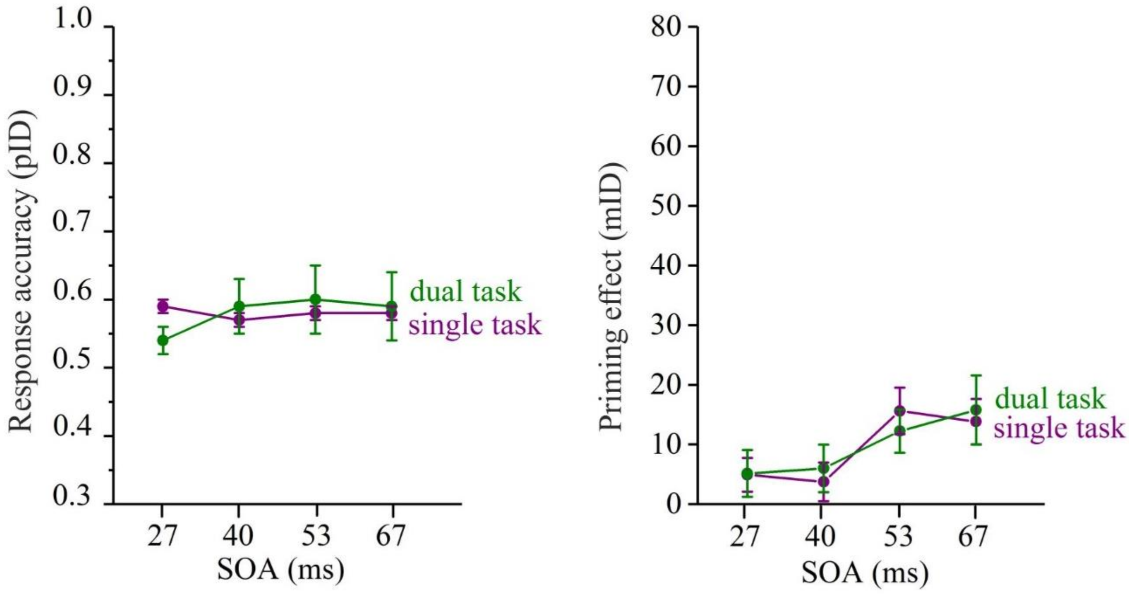

Figure 33. Experiment 3. *Left:* Average response accuracy in the prime identification task. *Right:* Average response-time priming effects in the mask identification task.

Conclusion

In Experiment 3 priming effects in response times and error rates were found in both single and dual tasks, even though they were relatively small. Unfortunately, no dissociation between priming and prime discrimination was observable, neither in the single nor in the dual task. Since prime discrimination performance was constant and quite similar under the single and dual task, it seems most likely that the mixed task sessions guaranteed equal practice for both task types. Alternated task sessions seem to prevent a dual task advantage, as it was observable when sessions of the dual task were performed after single task sessions (Experiment 2).

Still, under dual-task conditions the microstructure of response priming effects is altered, and criteria for fast feedforward processing as suggested by Rapid-Chase Theory are violated: responses were on average 106 ms slower and fast errors were lost compared to the single task. Furthermore, error responses in inconsistent trials were neither time-locked to the prime nor the mask (nevertheless, this was also the case for single tasks). Again, these findings suggest that fast and automatic feedforward processes are harder to guarantee under dual than single tasks. Hence, increasing priming effects will probably occur less frequently under dual-task conditions, so that a crucial factor for a possible dissociation between an indirect measure of priming and a direct measure of prime awareness is not respected. Consequently, dual tasks do not seem to provide the same conditions for fast response activation as single tasks, thus jeopardizing the chances to find a dissociated data pattern. Accordingly, the results of Experiment 3 once again indicate that the individual data analysis is a critical factor in finding a possible dissociation between priming and prime awareness; and moreover, it is usually more informative than the averaged data pattern.

3.5 Discussion Part II

Objective versus subjective measures of visual awareness. Experiment 1 compared objective prime discrimination performance (prime ID) and subjective ratings on the Perceptual Awareness Scale (Ramsøy & Overgaard, 2004) in single and triple tasks. On average, performance in prime ID was markedly higher in the triple than the single task and decreased with SOA.[49] Subjective ratings on the PAS were relatively more constant over conditions at an average level roughly corresponding to the rating category “brief glimpse”. At first glance, this pattern seems inconsistent with the claim that subjective measures like the PAS are as sensitive as objective measures of performance (e.g., Avneon & Lamy, 2018; Lamy et al., 2015, 2017; Peremen & Lamy, 2014). However, it is necessary to consider the data pattern of individual observers, since it turned out that averaged masking functions can be misleading due to idiosyncratic individual time courses (e.g., type-A and type-B masking functions). Although overall masking functions decreased with increasing SOA, the individual masking patterns showed heterogeneous time courses: mostly decreasing with SOA, but also increasing or staying near chance level. In more detail, of eight observers, four showed a decrease in prime ID performance with SOA, in some cases over the full range of the scale. Two more observers performed at chance level throughout, one high-performing observer showed a slight increase, and one low-performing observer was at chance in the single task but slightly better in the triple task. If awareness ratings are compared with objective discrimination performance, it is revealed that increased, decreased and low constant values in prime ID and PAS ratings co-occur in the same observers, indicating that both measures do have some sensitivity to experimental conditions. However, ratings on the PAS of “absolutely clear image” and "no experience" rarely occur even if observers perform perfectly or near chance in the objective measure, and objective chance performance seems to be associated with ratings of "brief glimpse" rather than "no experience". Compared to objective prime discrimination effects, PAS effects seem compressed towards medium values, suggesting that the PAS scale is not good at capturing extreme values of visibility.

Moreover, there were some striking discrepancies between the measures: three observers (1, 5, and 7) performed better under triple-task than under single-task conditions

[49] As mentioned, this triple task advantage was most likely caused by the decision to perform the triple-task sessions after the single-task sessions to give the more challenging multitasks the benefit of optimal practice.

in the objective measure, but showed the reverse order in the subjective measure. This reversal implies that that these two measures cannot register exactly the same information. Possibly, observers may use perceptual cues to identify the prime that the PAS simply does not ask about – in other words, there would be a mismatch between the wording of the PAS labels and the criterion content (Kahneman, 1968). Other examples of perceptual cues would be percepts like rotation or expansion in the prime-mask sequence that can help to infer the prime (Albrecht & Mattler, 2012; Koster et al., 2020; T. Schmidt, 2000). If observers use the PAS labels literally, they may still give truthfully low visibility ratings because the objective performance does not derive from prime visibility in the first place but from such auxiliary cues. For instance, an observer may have a clear impression of rotation in the prime-mask sequence despite getting only a "brief glimpse" of the prime. Similarly, an observer may truthfully report a "brief glimpse" indicating that the prime was detected, even if it could not be discriminated.

A subjective scale with high validity would have a large overlap with the observer's criterion content, while a scale with low validity might fail to capture the criterion content entirely.[50] The study of Ramsøy and Overgaard (2004) shows how this requirement can be implemented in practice. They introduced their scale in an experiment where the critical stimulus was one of three shapes appearing in one of three colors and at one of three positions. Their perceptual awareness scale was applied separately to each of those stimulus dimensions, which means that the feature of interest was specified first and then the scale was applied specifically to it (e.g., "clear impression of the location", "brief glimpse of the shape", "brief glimpse of the color"). Such specification should increase the likelihood that the scale labels have some large overlap with the actual criterion content (or maybe that the observer deliberately uses the criterion content that the scale intends to measure). In Experiment 1, the subjective awareness scale asked rather unspecifically about the visual perception of “the stimulus” instead of asking about “the shape of the stimulus”, leaving it entirely free to the participant to fill this cypher with perceptual meaning. As Sandberg et al. (2010) have pointed out, “the specific manner in which one measures awareness matters …”, concluding that “*what you get is what you measure* [emphasis added]” (p. 1077). This is in line with the findings of Szumska et al. (2019) that differences in the sensitivity index (d') between prime localization and prime identification tasks demonstrate “that a lack of prime awareness in one task …” does not imply “no

[50] The same applies to objective measures.

awareness in another task" (p.12). Because both types of measures differ in the prime feature of interest (localization: "where" vs. identification: "what"), and apart from the fact that they can be categorized as objective measures, it once more shows the need for the term 'awareness' to be specified (e.g., awareness of stimulus location, awareness of stimulus color etc.).

How can you prevent indirect and direct measures from comparing apples to oranges? In the context of the current study, researchers need to focus on the critical stimulus feature that generates the priming effect – here it is the distinction between square and diamond primes. This critical feature would establish a dissociation between the indirect measure (e.g., response priming effects) and the direct awareness measure. Any other measure would lead to a mismatch between direct and indirect task (D-I mismatch, T. Schmidt & Vorberg, 2006).[51] This consideration implies that the PAS can rarely just be applied as it is: It needs to be combined with a clear instruction which aspect of subjective experience is to be rated, as Ramsøy and Overgaard (2004) did in their original study.

Koster et al. (2020) provide recent research on the issue of criterion content, demonstrating that the subjective experience of an observer is multidimensional and therefore not adequately captured by any kind of one-dimensional measure (no matter whether objective or subjective). However, the authors are aware of the fact that "such a restricted focus is justified in empirical contexts" (p. 2), for instance in studies of unconscious response priming. Here, "an assessment of conscious access of those stimulus features that potentially drive the priming effects" (p. 2) would have been necessarily required.

Averaged data versus individual data. As a matter of fact, masking functions are idiosyncratic and differ between observers, mostly resulting in two types with either an increasing or an u-shaped time course (type-A or type-B masking functions, Albrecht et al., 2010; Albrecht & Mattler, 2012, 2016; see also Breitmeyer & Öğmen, 2006). For this reason, it is advisable to analyze individual data precisely and in depth[52]. As demonstrated, individual data patterns are more informative with regard to a double-dissociated time course of priming and masking. This supports the idea of a preselection into type-A and type-B observers on the basis of a pilot session, a method that has been used successfully

[51] This idea will be discussed in more detail in Section 4.4 "Double dissociations and criterion content".

[52] Averaged data, however, should be treated with caution since critical effects might be overestimated although they depend on only a small number of observers, but with large effects (Smith & Little, 2018).

by Albrecht and colleagues (e.g., Albrecht & Mattler, 2012; Albrecht et al., 2010). From the current findings, it can be concluded that if there is a potential for a possible dissociation between two measures, for instance priming and prime awareness, it can most probably be found at the level of individual observers.

Feedforward processing and multitask settings. Experiment 1 clearly shows that the triple-task situation interferes with response priming, since a double dissociation was lost under conditions of the triple task. Most participants (except for the clearly increasing pattern of Participant 2) showed slightly decreasing priming effects with increasing SOA, while Participant 3 and even more Participant 6 showed the strongest decrease of effects within the two shortest SOAs, most prominently affecting the overall priming pattern. Additionally, the analysis of the microstructure of priming effects revealed that a critical factor for it, the rapid feedforward processing, was mostly not guaranteed under conditions of the triple task. This was also obvious under conditions of the dual task (Experiment 2 and 3), where the microstructure of effects was also alternated and pure feedforward processing was harder to guarantee compared to the single task. In a nutshell, priming effects should always be analyzed on a micro-level (e.g., checking the presence of fast errors, the time-locking of errors in inconsistent trials to the prime, or the emergence of slow errors on consistent trials as an indicator of response inhibition) if the data is to be investigated for possible dissociations between priming and prime awareness.

The loss of double dissociation under triple-task conditions is consistent with the findings of Peremen and Lamy (2014), who reported u-shaped priming functions in tandem with u-shaped masking functions under triple-task conditions. However, within the same context they conclude that differences in attention rather than in conscious perception might account for a dissociated time course in single tasks. This suggests that the single-task measurement created an artifact in attentional employment: the authors seem to expect that priming effects should increase with SOA whenever attention is fully directed to the mask (e.g., as in singly performed tasks), but decrease with SOA when attention is shared with the prime (e.g., as in a triple task). This is inconsistent with several studies that investigated the effect of different aspects of attention on the time-course of response priming. When primes and masks appear at an unattended location, priming effects are smaller and responses are slower compared to an attended location, but they still increase with SOA (T. Schmidt & Seydell, 2008; cf. Sumner et al., 2006). The same modulation of priming effects occurs when a non-positional feature (e.g., a color or a shape) is cued, even if the prime remains indiscriminable (F. Schmidt & T. Schmidt, 2010). Finally, directly varying prime and target contrast independently modulates priming effects and overall response time but does not reverse the time course of priming (Vath & Schmidt, 2007). Thus, what happens in the triple task cannot be described by a simple reallocation of visual attention. Rather it seems that the need to divide attention causes massive cognitive costs (Pashler, 1989, 1994b) associated with higher working memory load and cognitive control. The triple task requires participants to attend to three different aspects of the trial: the *shape of the mask*, the *shape of the prime*, and the *subjective impression of prime clarity*. Whereas speeded responses to the mask would normally be automatized, the two direct measures require consideration of multiple sources of information. Therefore, all relevant information must be held in working memory while a sequence of three responses is scheduled. In this process, most participants prioritize the prime-related responses, as suggested by the fact that prime discrimination performance does not suffer from the triple task. Instead, the prioritization seems to be entirely to the detriment of the speeded mask ID task. Experiment 1 clearly shows that the triple task leads to a structural change in priming effects: As compared to the single task, responses to the mask are slowed by more than 160 ms, the priming effect is decreasing with SOA instead of increasing, fast errors disappear, and error response times are no longer time-locked to the prime (or any other stimulus). Fast errors are one of the indicators that response priming is feedforward: Because Rapid-Chase Theory assumes that the earliest responses are controlled exclusively by the prime, it predicts that prime-provoked errors should be as fast as the fastest correct responses (T. Schmidt, 2014).

The slowing of responses also explains the otherwise puzzling finding that priming effects decrease with SOA under triple-task conditions. If the prime-mask SOA is prolonged or if responses occur very late, they are often subject to response inhibition. Response inhibition cannot only reduce the magnitude of the priming effect, but even reverse it such that responses are faster in inconsistent than in consistent trials (*negative compatibility effect or NCE*; Eimer & Schlaghecken, 1998, 2003; see Sumner, 2008, for a review). T. Schmidt, Hauch, and F. Schmidt (2015) show that the NCE in pointing movements results from inhibition of the primed response and activation (or disinhibition) of the opposite response, as shown by late errors that start in a spatial direction 180° opposite to both the prime and target direction (cf. Boy et al., 2010; Jaśkowski & Przekoracka-Krawczyk, 2005). Panis and Schmidt (2016) analyze the NCE in keypress responses and find that it is associated with late errors in consistent trials starting about 320 ms after mask onset (in a sequence of prime, mask, and target). Importantly, the NCE is most pronounced in slow responses (Atas & Cleeremans, 2015; Ocampo & Finkbeiner, 2013), and a reanalysis of the priming effects in the triple task of Experiment 1 reveals that the later the decile of the response time distribution (calculated separately for participants and conditions), the more pronounced the decrease in priming with SOA. It seems that inhibition of the primed response is the most likely source of the altered time-course of priming in the triple task. In sum, it seems that the triple-task situation does not prevent priming effects altogether, but it leads to a structural change in priming that is no longer consistent with sequential feedforward response activation by primes and masks. Instead, the data suggest that priming now occurs out of a memory representation under high cognitive load and is subject to response inhibition. But if feedforward response activation is independent of awareness because it works without recurrent processing (Lamme & Roelfsema, 2000), disrupting the feedforward mechanism of priming would eliminate the necessary conditions for priming without awareness.

4. General discussion

4.1 The present thesis: Motivation, aims and scope of the work

A double-dissociated data pattern most powerfully demonstrates that a certain manipulation has opposite effects on two types of measures, providing strongest evidence that these effects cannot be based on the same processes (T. Schmidt & Vorberg, 2006). Hence, to demonstrate that visual processing of some critical stimulus information (e.g., color) is feedforward while visual awareness of this critical information needs neuronal feedback processing (assumptions of Rapid-Chase Theory, T. Schmidt et al., 2006, 2011; T. Schmidt, 2014; see also Lamme & Roelfsema, 2000; Lamme, 2010), a double dissociation between these two processes is most convincing. Still, simple-dissociated data patterns are historically used to demonstrate perception without awareness, showing a clear nonzero effect of some behavioral measure paired with an awareness measure that shows no effect, indicating the absence of awareness. As shown by Schmidt and Vorberg (2006), convincingly proving zero awareness of a direct measure includes strong measurement assumptions. Double dissociations, in contrast, do not suffer from such restrictions since they do not have to prove null sensitivity of the awareness measure (T. Schmidt & Vorberg, 2006). Nonetheless, double dissociations in visual science suffer from a different handicap, their demonstration is limited by specific experimental conditions (Breitmeyer & Öğmen, 2006; see also F. Schmidt et al., 2011; T. Schmidt & Vorberg, 2006), which seemingly devalues them to a less favorable data pattern.

Motivated by this fact, it has been one aim of the present work to increase the value and popularity of double dissociations in this research field as one of the most convincing data patterns to show that perception can be independent from visual awareness. Therefore, I investigated how the time course of a direct measure of stimulus awareness and an indirect measure of stimulus processing will be affected by changes in the experimental environment. How strongly do both measures depend on these experimental factors? Can a double dissociation be obtained?

For this purpose, I used response priming effects as an indirect measure of stimulus processing while the level of stimulus visibility under metacontrast masking served as a direct measure of awareness. Within the first set of experiments (Part I: Induced dissociations, Chapter 2), I coupled two independent variables, mask contrast and SOA that are known to have an influence on both measures. The results revealed that a double dissociation can be induced: while response priming effects were unaffected, still increasing over time, masking effects as a direct awareness measure showed a decreasing or u-shaped pattern. The results provide further evidence for the assumptions of Rapid-Chase Theory that priming effects are based on fast feedforward processing, unaffected by backward masking, while awareness seems most likely to be based on feedback mechanisms since metacontrast masks affect the time course of stimulus visibility.

In the second set of experiments (Part II: Double dissociations under pressure, Chapter 3), I applied both direct and indirect measures within the same trial or separately, and used two types of direct measures (objective vs. subjective) of awareness. The findings demonstrated that the application of both measures within the same trial has unfavorable effects on a double-dissociated pattern: fast feedforward processing is impaired, resulting in a changed microstructure of priming effects. Nonetheless, priming and masking effects were double-dissociated under conditions where direct and indirect measures were applied separately. Moreover, the experiments have shown that objective and subjective awareness measures capture different aspects of visual information, most often incongruently with the observer's criterion content (Koster et al., 2020).

Actually, in both sets of experiments a double-dissociated pattern between priming and masking is most impressively demonstrated at the level of single observers. Although this may sound trivial, it critically questions the commonly used practice of data analysis at an averaged group level. Moreover, the present work shows that a double-dissociated pattern between visual stimulus processing and visual awareness is an individual phenomenon, since (metacontrast) masking effects highly depend on the observer (Albrecht & Mattler, 2010, 2012, 2016). For this reason, I will concentrate on critical aspects that should be considered more within the research field of visual perception (e.g., Small-*N* designs with a deep analysis of few observers, criterion content, etc.), so that a double-dissociated pattern between two measures no longer has to be a rarity in the future.

4.2 Double dissociations analyzed at group level and individually

In the context of this work, data were analyzed individually at the level of single observers, and at group level (averaged across participants). This procedure was applied for the priming effects of the indirect measure, as well as masking effects of the direct awareness measure. In general, the experiments have demonstrated that the pattern of response priming effects are quite homogenous across individual observers[53] (mostly increasing over SOA), while masking functions are idiosyncratic and differ markedly between individual observers.

The first set of experiments (Part I: Induced dissociations, Chapter 2) has clearly shown that the time course of masking functions very much depends on an individual observer, supporting empirical findings of Albrecht and colleagues (Albrecht et al., 2010; Albrecht & Mattler, 2012, 2016). This furthermore highlights the fact that masking is influenced by many factors (e.g., mask energy, Breitmeyer & Öğmen, 2006; Aydin et al., 2021; stimulus size and orientation, Bridgeman & Leff, 1979; see also Duangudom et al., 2007; SOA, Kahneman, 1967). The results of all three experiments have demonstrated that regardless of which kind of mask-contrast function (low, high, increasing or decreasing MCF) is used, at the level of individual observers masking effects always show a heterogeneous pattern while priming effects are more homogeneous across participants and different MCFs. This finding is most impressively shown under conditions of uncoupled masks in Experiment 2 and 3. Here, the ability of the imperative stimulus to mask the prime is decoupled from its ability to activate the response, and response priming effects most clearly demonstrate the characteristically increasing pattern. Still striking, masking effects differ greatly between observers, showing a mixture of type-A and type-B masking functions. Hence, at the level of individual observers' double dissociations between priming and masking are observable, demonstrating the effectiveness of the method, while at the group level floor effects of most of the participants spoil any chance of a double dissociation. This is also evident under conditions of coupled masks in Experiment 1 and 3. Although the masking aspect of the imperative stimulus is coupled to its response-activation aspect, priming functions still show a rather homogeneous pattern across participants while masking functions markedly differ between observers. However, a double dissociation is neither observable at the group nor at the individual level since priming effects do not clearly increase under these conditions. In both Experiments 1 and 3, using coupled masks under conditions of the increasing MCF, priming effects at group level decrease in exactly those conditions where prime discrimination performance is also lowest. Nevertheless, at the level of single observers, the dip at the 40-ms SOA is differently pronounced and for some observers less prominent than for others. This finding

[53] Nevertheless, variability between participants remains: Individual reaction times are localized at different levels (slow vs. fast RTs) and priming effects can be larger or smaller for the respective observers.

suggests that observers respond differently to the manipulation of mask contrast, and to the method of induced dissociations. Still, within this set of experiments marked differences between masking functions are most apparent at the level of individual observers, while averaging individual data can blur critical differences. Thus, without the additional analysis of individual effects, analyzing data at group level only could have led to the assumption that the method of induced dissociations might not work.

The second set of experiments (Part II: Double dissociations under pressure, Chapter 3) suggests even more that a further analysis at the level of single observers seems to be a useful method to find prominent differences within the time course of masking functions (type-A vs. type-B). For the demonstration of a double dissociation, the time course of masking should form a decreasing or u-shaped type-B function (despite an increasing priming function). In Experiment 1, the typical u-shaped time course of the masking function is actually most apparent at the individual level, while at the group level masking functions of the respective task types are rather flat since some observers perform at a constant level across all SOAs. Consequently, averaged data can be misleading in this context. Conversely, in Experiment 2 the overall time course of masking effects forms an increasing (type-A) masking function. This is also evident at the level of single observers, where no decreasing (type-B) masking pattern can be observed. Here, individual masking patterns are well represented at the group level, but only because all participants exhibit type-A masking. However, if both masking types are included within the same sample, at the group level one of the two types might be overrepresented. As shown, the idiosyncrasy of masking functions will only become apparent at an individual level.

These two examples strongly support the idea of a preselection into type-A and type-B observers on the basis of a pilot session, a method that is used successfully by Albrecht and colleagues (e.g., Albrecht et al., 2010; Albrecht & Mattler, 2010, 2012). Otherwise, “luck” or chance will decide whether there are any type-B observers within the sample, and therefore whether a double-dissociated data pattern can be obtained or not. Judging from this perspective, and even though this is routinely practiced in the literature, it is not advisable to average masking functions that significantly differ within their time course at an individual level (type-A vs. type-B), especially not if a double-dissociated pattern between masking and priming is intended to be shown. The empirical findings of my work show that this applies to both types of double dissociations, to artificially induced double dissociations (Chapter 2) and to naturally occurring double dissociations

(Chapter 3). As a corollary, masking effects (as well as priming effects) should always be analyzed in depth at the level of single observers (individual data), and at the group level (averaged data) only after a preselection into type-A and type-B observer, proposing a use in tandem.

The strength of averaged data in statistics lies in reducing variation and increasing the general validity and generalizability. This is necessary when drawing conclusions about a population, for instance as seen in medical drug studies. Here, it is important that a specific drug has the same effect (e.g., an opposing effect between two processes: increasing the immune response to a specific viral protein while reducing autoimmune response) for the majority of the population and for the group of patients for whom it is intended. In this case, general validity is best shown by averaging data across all participants. In practice, this is mostly achieved by collecting and analyzing data of a large group of participants (Large-*N* design, Smith & Little, 2018). In contrast to Small-*N* designs (Smith & Little, 2018), where the data of few participants are collected and repeatedly measured with large precision, Large-*N* studies rarely analyze or plot individual data patterns of single participants[54].

Although it is not a common practice within the research field of visual perception to use a small sample of participants and check for individual time courses, the present work reveals that data analysis at the individual level of single observers is helpful for the demonstration of a double-dissociated pattern between two measures (here visuomotor processing and visual awareness). Now a critical reader may ask whether averaging data still makes sense within this context. The answer must be ‘yes’, because data patterns at group level can be helpful. Nonetheless, the results demonstrate that individual time courses are more informative: single and double- dissociated patterns between priming and masking are most impressively demonstrated at the level of single observers. Type-A and type-B observers that differ greatly within their time course of masking should not be averaged, because this variability of individual masking effects will lead to the difficulty that averaged masking data cannot be generalized to other (mixed) samples of observers, loosing validity. In general, the findings of my thesis clearly indicate that it is always advisable to look at individual data patterns of single observers, especially when different measures are compared regarding their time course; even more, when these measures are

[54] The benefits of Small-*N* designs are discussed in more detail in Section 4.3 “Small-*N* designs and double dissociations”.

supposed to show opposite effects. A preselection into different types or groups (e.g., type-A vs. type-B observer) seems to make sense whenever specific and classifiable data patterns can be identified at the level of single participants. These types should be analyzed separately and better not be mixed. Only then averaged data can maintain its informative value and meaningfulness.

4.3 Small-*N* designs and double dissociations

"Sometimes, less is more …" (Normand, 2016, p. 3). The psychophysical tradition follows this principle by mostly applying Small-*N* designs were only a few participants are repeatedly measured and analyzed with great precision instead of using large groups of participants (Large-*N* design, Smith & Little, 2018). Although Small-*N* designs have a long tradition, which according to Smith and Little (2018) reaches back to foundational studies by Fechner, Ebbinghaus, Pavlov, and Thorndike, it is steadily exposed to discussions about a lack of statistical power and the problem of replicability (e.g., Baker et al., 2021; Normand, 2016; Open Science Collaboration et al., 2015; Smith & Little, 2018). In order to overcome what Smith and Little (2018) call the *replication crisis*, several suggestions have been made. For instance, Benjamin et al. (2018) advocate to lower the threshold of statistical significance from $p \leq .05$ to $p \leq .005$. This, however, would have to result in a much larger sample size (an increase of 70%) to achieve 80% power (Smith & Little, 2018), seemingly incompatible with science practice (Lakens et al., 2018 describe some likely negative consequences of this claim, which could be harmful to common scientific work, e.g., an increase in funding and effort for time- and resource-intensive data, a decline of studies with unique populations, etc.). Further, this debate about an optimal sample size is boosted by the fact that some leading journals seem to favorably publish work that is based on large samples (Smith & Little, 2018).

Notwithstanding, a recently published article by Baker et al. (2021) demonstrates that an optimal combination of number of trials and the number of participants can yield statistical power[55], supporting the notion that testing a small number of participants (Small-*N* design) must not necessarily lead to a loss of power when measurement precision (number of trials) is at an optimal level. As noted by Smith and Little (2018), in Small-*N*

[55] The method of power contours (Baker et al., 2021) shows that statistical power can be obtained by various combinations of sample size and trial number.

designs "*the individual, rather than the group, becomes the replication unit* [emphasis by the authors]" (p. 2089); thus, the measurement of each single participant would be an independent replication of the experiment. They further argue that a small set of measurements with few participants does not have to be statistically underpowered, if the study uses a consistent set of measurements and carries out multiple replications. Then, as in the view of Smith and Little (2018), "to ascertain whether the same functional relationships and the psychological processes … are exhibited constantly across individuals" (p. 2089) would become "the goal of "replication" [quotation marks by the authors] …" (p. 2089).

The current thesis demonstrates that Small-*N* designs with an individual analysis of few observers are favorable when the goal is to show effects that are highly observer-dependent and idiosyncratic like masking effects under metacontrast, and even more if these effects are directly compared to another measure (e.g., priming effects) as realized in the dissociation procedure. Here, the time course of both measures is a critical factor to assess whether the effects are dissociated or not. Generally, and as the pattern of averaged data actually revealed (see also Normand, 2016 where the hypothetical data of repeated measures for two subjects are used to argue in the same way), important features of the individual data can blur; a double-dissociated pattern observed at the level of single observers will maybe no longer be detectable at the group level. Undoubtedly, as Normand (2016) noted, averaging data would be a useful way to summarize stable and similar performances, however, the mere averaging of data in the sense of generalizability would be contrary to what good science should do: to depict a part of the real world which includes individual variation.

"Individuals behave, not averages. People don't respond "on average" [quotation marks by the authors], they respond a certain way at a certain time" (Normand, 2016, p. 2). In fact, studies that apply individual analysis of masking data at a level of single observers provide solid evidence that participants differ systematically and reliably in their masking functions (e.g., Albrecht et al., 2010; Albrecht & Mattler, 2012, 2016; Koster et al., 2020). Observers are classified according to their individual and characteristically time course into two different types, type-A or type-B. However, the masking literature has largely ignored the existence of idiosyncratic masking functions, still favorably using masking data that is averaged across all participants. Consequently, observer-dependent and significantly different time courses of type-A or type-B masking are not considered, but rather averaged together for group analysis. Still, the most informative way to gain information about a phenomenon that is highly limited by individual factors (e.g., type of observer), such as double dissociations, is an individual analysis or a use in tandem with group data. A deep analysis with great measurement precision of individual effects is best (if not only) realized by a Small-N design. The strength of such a design has been revealed within this work. Particularly, at the level of single observers it was shown how little the pattern of masking effects predicts the patterns of priming effects, once again providing evidence that their underlying mechanisms must be based on different neuronal processing patterns (feedforward vs. feedback).

Nonetheless, a critical reader might note that the difficulty to generalize the masking data (but not the priming data) still exists, and that data can hardly be transferred to other samples of observers. This critical remark would be completely correct; however, this problem cannot be healed by adding more observers. Actually, as noted earlier these observers would be expected to differ too, keeping in mind that the distinction between two specific types of masking functions has been made in the literature (e.g., Breitmeyer & Öğmen, 2006; see also Albrecht & Mattler, 2010, 2012, 2016). Thus, without a general preselection into these two classes of masking types, adding more idiosyncratic masking patterns into the pot of aggregated data will not solve this generalization problem.

As mentioned, a double-dissociated time course of masking and priming effects is rare since it is sensitive to person-dependent factors (e.g., criterion content, type of observer). As a corollary, a double dissociation between a measure of stimulus processing and a measure of stimulus awareness that clearly indicates the independence of both processes is most impressively demonstrated at the level of single individual observers (maybe also at the group level, but separated by type-A and type-B observers). Although I judge from this perspective, I do not claim that averaging data is in general not a good idea; rather arguing that a double dissociation between visual perception and awareness is such an individual phenomenon that the analysis at the individual level does always make sense, advocating the use of Small-*N* designs in this research field. Results that come from careful measurement with high precision of few participants should experience more acceptance, because less is sometimes more.

4.4 Double dissociations and criterion content

Individual observers differ in their visual perception and thus in the way they use visual information to perform a task. Kahneman (1968) introduced the concept of criterion content to describe that participants in psychophysical experiments may use a visual information that differs from the visual information which the experimenter intends to measure. This problem mostly arises when the observer tries to transfer his/her own personal phenomenological experience onto the experimenter's measure at hand (Kahneman, 1968). If the measure is not valid, or in other words, if the measure does not ask for the visual information that the observer actually uses, then the observer will fail to use the measure appropriately. The following illustration intends to show how criterion content (Kahneman, 1968) and the logic of the dissociation paradigm are linked[56].

In the present work, shape or color stimuli are used as primes and metacontrast masks. Within the response priming procedure, the mask follows the prime, aiming to reduce prime visibility by its adjacent contours. In the mask identification task, participants gave speeded responses to the mask. Thus, participants either had to discriminate a square- from a diamond-shaped mask (*shape ID*), or a red-colored mask from a green-colored mask (*color ID*). According to Rapid-Chase Theory, the shape of the prime stimulus activates the response to the mask in the shape-ID task, while prime color activates the response to the metacontrast mask in the color-ID task. The priming effect serves as an indirect measure of stimulus processing, indicating the processing of prime shape or prime color. In this context, the *task-relevant feature* is either the shape or the color. Yet, the *critical feature* that drives the indirect effect is the difference between square and diamond in shape ID, and the difference between red and green in color ID. The critical feature is based on differences in the physical stimuli (e.g., differences in shape or color), and always defined by the processing characteristics of the indirect (priming) task. In other words, the critical feature should always drive the motor responses in the indirect task and should consequently cause the response priming effect. Because the direct task is used to measure visual awareness of the prime (exactly the stimulus that

[56] Some of the ideas, concepts, terms and definitions are based on the manuscript submitted for publication, and are adjusted to my present thesis: Schmidt, T., & Biafora, M. (2021). *A theory of visibility in the dissociation paradigm* [Manuscript submitted for publication]. Department of Psychology, University of Kaiserslautern. For this reason, the wording might be similar.

drives the motor response in the indirect task), it is necessary for validity and crucial for the logic of the dissociation paradigm that the direct task measures the critical feature. Otherwise, there is a mismatch between the tasks (D-I mismatch, T. Schmidt & Vorberg, 2006).

How do the concept of criterion content and the idea of the critical feature match together? What is the link between them? While the critical feature is anchored to the physical stimulus characteristics of the indirect task, Kahneman's (1968) concept of criterion content can rather be understood as an internal, abstract construct inside the cognitive system of an observer. Depending on which source of visual information is actually used by the observer while performing the task, an observer's personal criterion content is individually formed by the use of perceptual cues (Albrecht & Mattler, 2012, 2016). As mentioned, it is crucial for the logic of the dissociation paradigm that both indirect and direct tasks measure the critical feature. In this context, criterion content is a set of perceptual cues, where only one perceptual cue directly corresponds to the visual awareness of the critical feature, the *critical cue*. Consequently, in order to avoid a mismatch between the direct and indirect measure it is necessary that task instructions or scale labels of the direct measure are adapted to the task-relevant feature (e.g., shape) defined by the indirect task, trying to integrate its critical feature (square vs. diamond), aiming to encourage the observer to use the critical cue. I suppose that only then a high level of validity can be obtained. Still, it can never be guaranteed that the observer actually uses the critical cue, as there are other perceptual cues available which can also be helpful (maybe even more helpful) to perform the task. For instance, the observer is asked to discriminate the prime shape (e.g., square vs. diamond) within a prime-target stimulus sequence. Instead of the critical cue, the observer can choose any other perceptual cue from the set of available cues (criterion content). Then, the observer may use the visual information of a perceived flicker or rotation within this stimulus sequence to infer the shape of the stimulus. Consequently, this chosen perceptual cue helps the observer to perform the task; however, it is not the critical one but rather some other type of perceptual cue. Still, the observer is able to successfully perform the task, but without consciously perceiving the physical shape of the prime, which would be necessary for the observer when he/she uses the critical cue. Although the observer can discriminate the critical feature within the direct measure (e.g., shape), the use of other perceptual cues than the critical one (which is the only one that is directly linked to the critical feature) threatens validity of the direct measure.

The empirical findings of the second set of experiments (Chapter 3) demonstrate how closely Kahneman's (1968) concept of criterion content, the theoretical assumptions about the critical feature and critical cue are linked to double dissociations. In Experiment 1, objective and subjective tasks are used as direct measures of prime awareness; visuomotor processes activated by the prime are measured in an indirect response priming task. In the direct objective discrimination task, observers had to discriminate whether the prime shape (task-relevant feature) was a square or a diamond (critical feature that drives the indirect effect). Here, the participants' responses are classified as correct or incorrect since they can be compared with the actual and physical stimulus aspects (square vs. diamond), which is why this objective prime shape discrimination task most likely asks exclusively for the critical cue. Under these conditions, it is assumed that the observer is most likely encouraged to use the critical cue in the direct task (even though this can never be guaranteed), most probably preventing a D-I mismatch (T. Schmidt & Vorberg, 2006). Although objective measures can easily formulate task instructions that directly ask about the critical feature (what might increase the chance that the observer uses the critical cue), however, some objective measures require a careful handling or should better be avoided. For instance 'yes-no detection' tasks (e.g., Vorberg et al., 2003). In the dissociation paradigm indirect measures mostly employ discrimination rather than detection tasks, since the physical difference between the stimuli drives the indirect effect. For this reason, a direct measure that is based on the sole detection of the prime stimulus instead of the discrimination between the stimulus expressions (e.g., red vs. green), can lead to the problem that the observer will not use the critical cue but some other perceptual cue. Within a yes-no detection task, the critical stimulus feature (e.g., the distinction between shapes) must not necessarily form the basis of the observer's response, since the mere detection of any kind of visual information can cause a 'yes'- detection by the observer. Hence, a successful performance of the direct task does not require the use of the critical cue; any other perceptual cue within the criterion content can be used as well. Actually, it is very likely that an observer will choose that perceptual cue which is most helpful to perform the task. This is not always the critical cue, since other kinds of perceptual cues (e.g., rotation) might be more helpful for a pure stimulus detection. As a corollary, and within the dissociation paradigm, it is not advisable to use a detection task as direct measure of prime awareness. Still, if it cannot be avoided, task instructions should be carefully prepared, and should as precisely as possible be directly related to the critical stimulus feature. Only then, the likelihood that the observer may use the critical cue can be increased. This aspect can be illustrated by two conceivable task instructions:

1) “Please press ‘Yes’ if you can detect a square- or diamond-shaped prime and ‘No’ if you cannot (detect a square- or diamond-shaped prime)!”

2) “Please press ‘Yes’ if you can detect the prime stimulus and ‘No’ if not!”

While the latter example does not address the critical feature, the first one includes the two possible stimulus expressions, which is why appropriate instructions for detection tasks can highlight the critical feature and maybe more likely motivate the observer to use the critical cue. Other similar objective tasks (e.g., same-different distinctions) can lead to the same problem, whenever the critical feature is not well defined. While in the objective discrimination task observers respond to the physical stimulus characteristic (shape or color), observers had to rate their holistic visual impression of the prime on the Perceptual Awareness Scale (Ramsøy & Overgaard, 2004) in the direct subjective task. In contrast to the original study by Ramsøy and Overgaard (2004), the PAS used in the experiments was not specifically applied to the task-relevant critical feature (shape: square vs. diamond). Instead, the rating scale contained rather unspecific labels, where the four categories “no experience”, “brief glimpse”, “almost clear experience”, or “clear experience” had to be transferred to “*the stimulus*” as a whole unit (and not to the task-relevant stimulus feature or its critical feature). This procedure probably caused a mismatch between the wording of the scale labels of the PAS and criterion content. In Experiment 1 (Part II, Chapter 3) and within the same observer, different time course of both objective and subjective measures under conditions of the same task type (e.g., single task) lead to this assumption. Unexpectedly, an accuracy level of 50% correct responses under conditions of the objective measure is not associated with ratings of “no experience” in the subjective measure, but rather associated with ratings of “brief glimpse”. Thus, what most likely seems to happen is that the same observer uses different perceptual cues for the respective direct measure. In the objective discrimination task, the observer may use the critical cue, while in the subjective measure the same observer may use a perceptual cue that is more helpful than the critical cue, since the visibility ratings of some observers are higher under the same task conditions. Consequently, a participant can then truthfully report a “brief glimpse” in the subjective measure, indicating that “the stimulus” was detected (e.g., by a flickering or perceived rotation), even if the stimulus cannot be discriminated regarding its shape. Considered post hoc, this is not surprising because the PAS was applied without any specification of the critical feature within the scale labels, leaving it entirely open to the observer which visual information will be used. Under conditions of the triple task (Experiment 1, Part II), the indirect measure (mask ID task) and the two direct measures (prime ID task, PAS rating) are performed within the same trial. Hence, the observer must perform three tasks in a row, still instructed for the indirect task to respond as quickly and as accurately as possible, and to respond without time pressure in the two direct tasks. An optimal observer should try to maximize performance for all three tasks. Thus, the observer may feel compelled to use some kind of performance strategy that may require the use of a perceptual cue that is most helpful to successfully perform all of the three tasks. Possibly, in this case, the critical cue is not the most helpful perceptual cue.

In the context of the current thesis, I assume that the critical feature constitutes a key element to avoid a mismatch between the two measures within the dissociation paradigm. The critical feature is defined by the indirect measure and thus directly anchored to the critical cue within the criterion content. It is this critical visual information that should be measured by the direct task. This consideration also implies for future studies that the PAS (Ramsøy & Overgaard, 2004) can rarely be applied as it is; the four original scale labels need to be combined with aspects of the critical feature of the task-relevant stimulus. Therefore, the PAS would have to be extended and adjusted, constituting a bipolar rating scale (cf., Haberkamp et al., 2019) with seven categories:

“Clear experience of a *square*” – “Almost clear experience of a *square*” – “Brief glimpse of a *square*” – “No experience of a *square* or a *diamond*” – “Brief glimpse of a *diamond*” – “Almost clear experience of a *diamond*” – “Clear experience of a *diamond*”

The poles could be composed of the two “extreme” values with the label “Clear experience of …” and the various gradations in between. Furthermore, each label should be assigned a value, which however, should not be associated with the degree of visibility or clarity (e.g., -3 = “Clear experience of a square”, 3 = “Clear experience of a diamond”).

For this reason, it is advisable to use a response box instead of the digit keys on a computer keyboard. Although this type of bipolar rating scale clearly includes the shape expressions of the critical feature, it does not constitute a pure subjective measure. By integrating the critical feature “square” or “diamond”, the measure takes on an objective character with aspects of the physical stimulus, while the magnitude of the rating forms the subjective part of the measure. Alternatively, a pure subjective measure could ask, “Please rate how clearly you saw whether the shape of the prime was a square or a diamond”. Then, the critical feature is included within the task instruction, but the observer does not have to choose any of the shape expressions.

Based on the above findings, I finally conclude that it is essential for the logic of the dissociation paradigm, to avoid a mismatch between any kind of indirect measure (e.g., discrimination- or detection task) and any kind of direct measure (e.g., objective or subjective task). This concerns the measurement validity as well as the meaningfulness of the data pattern in general: Any dissociation (no matter whether simple or double dissociation) between an indirect and a direct measure is only meaningful when the direct task measures the critical feature that drives the effect of the indirect task. As described, this requirement can be met by objective as well as subjective direct measures. Nonetheless, it seems that objective measures are more suitable than subjective measures to prevent a D-I mismatch (T. Schmidt & Vorberg, 2006) within the dissociation paradigm. Actually, in objective discrimination tasks (but not in detection tasks), observers respond the physical stimulus characteristics, exactly that critical feature (differences in the physical stimulus, e.g., shape or color) that drives the motor response in the indirect task. In contrast, subjective measures that are commonly used are based on reports of an internal state that cannot be validated with physical stimulus characteristics. Nonetheless, subjective measures can be adapted to ask for the task-relevant feature (e.g., “Rate the clarity with which you perceived the shape of the prime”), although the integration of the critical feature would imply a bipolar ratings scale as considered above, or the following instruction, “Please use the rating scale to assess how clearly you perceived the prime as a square or a diamond”.

Latest research on the individual phenomenological experience of a visual stimulus under metacontrast (Koster et al., 2020) demonstrates a multidimensional pattern of subjective experiences, which would be reflected by dissociated subjective and objective measures of visual awareness.

As suggested by Koster et al. (2020) this “*presents a challenge to the traditional dissociation paradigm* [emphasis added]”, since “*the multidimensional structure of visual experience emphasizes the need to measure appropriate aspects of phenomenological experience that are relevant to the indirect effects of the prime* [emphasis added]” (p.20).

For the traditional use of the dissociation paradigm, this implies that especially direct subjective measures are confronted with the challenge to depict the variety and diversity of visual experience of an observer, while at the same time the focus on the critical stimulus feature might naturally “restrict” the observer’s richness of visual experience.

4.5 Double dissociations: Possibilities and limits

Historically, researchers have focused on simple dissociations where the direct measure has to indicate null sensitivity while the indirect measure has to demonstrate a nonzero effect (T. Schmidt & Vorberg, 2006). Nevertheless, this type of dissociation is burdened with restrictions regarding the measurement process (see Section 1.4 “Double dissociations” for more details regarding the problem of zero-awareness, exhaustiveness assumption, etc., T. Schmidt & Vorberg, 2006; see also Reingold & Merikle, 1988) and to date still confronted with critique, for instance not convincingly (if ever) demonstrating null sensitivity of the direct measure. Actually, if the direct measure is not able to convincingly show null sensitivity, a conclusive demonstration of zero-awareness has also failed. For this reason, a simple-dissociated data pattern is maybe too weak to demonstrate perception without awareness, even though it is most commonly used for this purpose.

As argued, double dissociations are more powerful since they circumvent all these shortcomings: they do not require zero-awareness of the direct measures, because direct and indirect measure should ideally run in opposite directions, and they work under milder measurement assumptions (see Section 1.4 “Double dissociations” or T. Schmidt & Vorberg, 2006 for a detailed explanation). Thus, a double dissociation where two measures show opposite time courses provides strong evidence that both measures cannot both be based on the same source of (conscious) information (T. Schmidt & Vorberg, 2006). For this reason, a double-dissociated pattern most convincingly demonstrates that stimulus perception can be independent of stimulus awareness, and that these two processes are not necessarily linked.

In the context of my thesis, such a double dissociation is demonstrated by increasing response priming effects (indicating that the prime stimulus is processed), while at the same time the prime discrimination performance decreases over time (indicating that prime awareness decreases). Here, the ability to discriminate the prime cannot explain priming, supporting the assumption that priming effects are most likely based on fast feedforward processing of the stimuli, while a conscious perception (i.e., visual awareness) of the prime needs feedback processing (e.g., Di Lollo et al., 2000; Lamme et al., 2002; Lamme & Roelfsema, 2000).

Nonetheless, researchers must face the difficulty that naturally occurring double dissociations between priming and prime awareness are limited by the fact that they only occur when very specific factors apply (Breitmeyer & Öğmen, 2006; see also F. Schmidt et al., 2011; T. Schmidt & Vorberg, 2006). As demonstrated, the time course of masking (type-A vs. type-B) as a direct measure of prime awareness is highly observer-dependent, not least because the individually formed criterion content has a significant influence. A decreasing or u-shaped pattern of masking is only observable for type-B observers and one important factor for the demonstration of a double-dissociated pattern where one measure should show a decreasing time course while the other should increase. Consequently, the indirect measure has to demonstrate increasing effects, indicating that the prime and its visual information is processed. As strongly indicated by the experimental results, an increase of priming effects in the indirect measure seems only to be guaranteed when the stimuli are purely feedforward processed. Additionally and as suggested, even the most convincing data pattern of a double dissociation is only meaningful when the direct task measures the critical feature that drives the effect of the indirect task, ensuring validity of the measures. However, if these factors are considered, the power of a double-dissociated data pattern can be used to demonstrate that prime awareness is not necessarily generated when the prime is perceived and its visual information processed (i.e., perception without awareness).

As shown in the first experimental section (Chapter 2), double dissociations can be artificially induced by custom-made mask contrast functions (MCFs). Here, the two factors mask contrast and SOA are conjoined, knowing that one of these factors alone can affect the time course of masking. One intention of this method was to investigate if a decreasing type-B masking pattern can be obtained, suggesting that the conscious perception of the prime can be manipulated by systematically coupling an aspect of mask energy (i.e., mask contrast) with SOA. The results clearly show that the conscious perception of the prime (i.e., awareness) can be manipulated by the metacontrast MCFs; however, not affecting the prime's ability to activate fast visuomotor response, demonstrated by increasing priming effects[57]. This is in line with the assumption of Rapid-Chase Theory that under conditions of response priming visually presented stimuli are rapidly processed in a feedforward manner without generating a conscious percept of it. As supported by the findings of the current work, visual awareness of a stimulus, in contrast, seems to be based on other cognitive processes, namely feedback processing.

Furthermore, this method reveals the wide range of application, and that induced dissociations enjoy a more flexible character than naturally occurring dissociations, as the increase in likelihood to find a double-dissociated pattern shows. As discussed, the method of induced dissociations is of general utility, because it can be promisingly applied for instance to methods of masked semantic priming or techniques of binocular rivalry such as continuous flash suppression (for more details see Section 2.5 "Discussion Part I").

Still, a double-dissociated data pattern (no matter whether occurring naturally or induced) is *always* limited to show only the relationship between two measures. Notwithstanding, a double dissociation between two measures (e.g., priming and masking) is yet frequently misused to give evidence about "consciousness" in general, when it is present (conscious) or absent (unconscious). Hence, Irvine (2017) critically noted:

> *The simplistic move one often finds in consciousness research from dissociations found about very specific visual or cognitive phenomena to claims about consciousness is a big one ... little justification is given of why a particular result is relevant to consciousness and not say, to 'just' forced choice detection, or inhibition of semantic priming* [emphasis added]. (p. 99)

[57] In his dissertation, Becker (2018; see also Becker & Mattler, 2019) demonstrated that different masking techniques can affect priming differently. While backward pattern or metacontrast masks did not affect priming of semantical and perceptual features, forward masks strongly reduced priming effects. His findings provide further support that (at least perceptual) priming effects are based on fast and early neuronal responses (e.g., as assumed by Rapid-Chase Theory) since they can be disturbed by forward masks but not backward masks.

Consequently, a double dissociation only serves the purpose of explaining the specific correlation between the particular variables that are used as two measures of two processes. Therefore, the transfer to a universal concept such as consciousness must undoubtedly lead to the practice of “*bad science of consciousness* … [emphasis added]” (Irvine, 2017, p. 95). In conclusion, however powerful double dissociations may be they have to be limited to what they (can) really show; undoubtedly, they can be considered as one of the strongest evidences that, for example, two cognitive processes *cannot* be based on the same neural processing mechanisms. Thus, a double-dissociated pattern between an indirect measure that indicates stimulus processing (e.g., increasing priming effects) and a direct measure that indicates prime awareness (e.g., decreasing prime discrimination performance) can certainly be used to demonstrate visual perception without awareness.

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Appendix

A: Results for individual participants in Experiment 1 (Part II)

Table A1 and Table A2 hold the test statistics and *p* values for the individual main effects and interactions reported in graphical form in Figure 25.

Table A1: Test statistics, degrees of freedom, and p values for the main effects and interactions reported in Figure 25. The large number of denominator degrees of freedom is determined by the number of trials per participant. Note that these analyses aim to generalize to new trials from the same participant rather than to new participants.

P1				**P2**				**P3**				**P4**			
Response times:				Response times:				Response times:				Response times:			
F_S	(3, 3510)	= 2.672	p = .046	F_S	(3, 3333)	= 1.284	p = .278	F_S	(3, 3376)	= 11.922	p < .001	F_S	(3, 3257)	= 3.859	p = .009
F_C	(1, 3510)	= 3.088	p = .079	F_C	(1, 3333)	= 147.209	p < .001	F_C	(1, 3376)	= 17.958	p < .001	F_C	(1, 3257)	= 3.938	p < .047
F_T	(1, 3510)	= 1206.399	p < .001	F_T	(1, 3333)	= 1070.208	p < .001	F_T	(1, 3376)	= 1670.165	p < .001	F_T	(1, 3257)	= 1022.469	p < .001
F_{CS}	(3, 3510)	= 0.464	p = .707	F_{CS}	(3, 3333)	= 3.521	p = .014	F_{CS}	(3, 3376)	= 3.526	p = .014	F_{CS}	(3, 3257)	= 1.035	p = .376
F_{ST}	(3, 3510)	= 0.835	p = .474	F_{ST}	(3, 3333)	= 2.308	p = .075	F_{ST}	(3, 3376)	= 11.842	p < .001	F_{ST}	(3, 3257)	= 4.337	p = .005
F_{CT}	(1, 3510)	= 0.660	p = .417	F_{CT}	(1, 3333)	= 58.699	p < .001	F_{CT}	(1, 3376)	= 1.555	p = .213	F_{CT}	(1, 3257)	= 2.558	p = .110
F_{CST}	(3, 3510)	= 0.997	p = .393	F_{CST}	(3, 3333)	= 0.477	p = .699	F_{CST}	(3, 3376)	= 6.053	p < .001	F_{CST}	(3, 3257)	= 2.626	p = .049
Errors:				Errors:				Errors:				Errors:			
χ^2_S	(3, N=3597)	= 4.477	p = .214	χ^2_S	(3, N=3585)	= 1.810	p = .613	χ^2_S	(3, N=3575)	= 21.852	p < .001	χ^2_S	(3, N=3527)	= 0.113	p = .990
χ^2_C	(1, N=3597)	= 5.709	p = .017	χ^2_C	(1, N=3585)	= 48.499	p < .001	χ^2_C	(1, N=3575)	= 0.066	p = .798	χ^2_C	(1, N=3527)	= 0.250	p = .617
χ^2_T	(1, N=3597)	= 3.251	p = .071	χ^2_T	(1, N=3585)	= 2.092	p = .148	χ^2_T	(1, N=3575)	= 7.662	p = .006	χ^2_T	(1, N=3527)	= 0.214	p = .644
χ^2_{CS}	(3, N=3597)	= 1.337	p = .720	χ^2_{CS}	(3, N=3585)	= 4.604	p = .203	χ^2_{CS}	(3, N=3575)	= 10.272	p = .016	χ^2_{CS}	(3, N=3527)	= 4.857	p = .183
χ^2_{ST}	(3, N=3597)	= 11.422	p = .010	χ^2_{ST}	(3, N=3585)	= 2.293	p = .514	χ^2_{ST}	(3, N=3575)	= 4.237	p = .237	χ^2_{ST}	(3, N=3527)	= 5.816	p = .212
χ^2_{CT}	(1, N=3597)	= 1.065	p = .302	χ^2_{CT}	(1, N=3585)	= 25.494	p < .001	χ^2_{CT}	(1, N=3575)	= 0.812	p = .367	χ^2_{CT}	(1, N=3527)	= 0.316	p = .574
χ^2_{CST}	(3, N=3597)	= 2.567	p = .463	χ^2_{CST}	(3, N=3585)	= 3.732	p = .292	χ^2_{CST}	(3, N=3575)	= 3.507	p = .320	χ^2_{CST}	(3, N=3527)	= 0.892	p = .827
Response Accuracy in pID:				Response Accuracy in pID:				Response Accuracy in pID:				Response Accuracy in pID:			
χ^2_S	(3, N=3600)	= 9.996	p = .019	χ^2_S	(3, N=3600)	= 120.791	p < .001	χ^2_S	(3, N=3600)	= 256.392	p < .001	χ^2_S	(3, N=3600)	= 1.997	p = .573
χ^2_T	(1, N=3600)	= 82.437	p < .001	χ^2_T	(1, N=3600)	= 272.129	p < .001	χ^2_T	(1, N=3600)	= 104.626	p < .001	χ^2_T	(1, N=3600)	= 2.760	p = .097
χ^2_{ST}	(3, N=3600)	= 4.494	p = .213	χ^2_{ST}	(3, N=3600)	= 4.687	p = .196	χ^2_{ST}	(3, N=3600)	= 29.652	p < .001	χ^2_{ST}	(3, N=3600)	= 2.370	p = .499
Ratings on PAS:				Ratings on PAS:				Ratings on PAS:				Ratings on PAS:			
F_S	(3, 3592)	= 141.770	p < .001	F_S	(3, 3592)	= 112.209	p < .001	F_S	(3, 3592)	= 827.639	p < .001	F_S	(3, 3592)	= 0.310	p = .819
F_T	(1, 3592)	= 1945.052	p < .001	F_T	(1, 3592)	= 144.957	p < .001	F_T	(1, 3592)	= 44.493	p < .001	F_T	(1, 3592)	= 89.084	p < .001
F_{ST}	(3, 3592)	= 59.764	p < .001	F_{ST}	(3, 3592)	= 22.066	p < .001	F_{ST}	(3, 3592)	= 33.832	p < .001	F_{ST}	(3, 3592)	= 1.336	p = .261

Table A2: Test statistics, degrees of freedom, and *p* values for the main effects and interactions reported in Figure 25. The large number of denominator degrees of freedom is determined by the number of trials per participant. Note that these analyses aim to generalize to new trials from the same participant rather than to new participants.

P5			
Response times:			
F_S	(3, 3393)	= 0.863	$p = .459$
F_C	(1, 3393)	= 49.261	$p < .001$
F_T	(1, 3393)	= 6951.189	$p < .001$
F_{CS}	(3, 3393)	= 2.167	$p = .090$
F_{ST}	(3, 3393)	= 4.181	$p = .006$
F_{CT}	(1, 3393)	= 18.831	$p < .001$
F_{CST}	(3, 3393)	= 2.079	$p = .101$
Errors:			
χ^2_S	(3, N=3576)	= 1.213	$p = .750$
χ^2_C	(1, N=3576)	= 16.271	$p < .001$
χ^2_T	(1, N=3576)	= 28.213	$p < .001$
χ^2_{CS}	(3, N=3576)	= 2.250	$p = .522$
χ^2_{ST}	(3, N=3576)	= 1.858	$p = .602$
χ^2_{CT}	(1, N=3576)	= 0.030	$p = .863$
χ^2_{CST}	(3, N=3576)	= 0.967	$p = .807$
Response Accuracy in pID:			
χ^2_S	(3, N=3600)	= 534.715	$p < .001$
χ^2_T	(1, N=3600)	= 27.119	$p < .001$
χ^2_{ST}	(3, N=3600)	= 11.689	$p = .009$
Ratings on PAS:			
F_S	(3, 3592)	= 684.138	$p < .001$
F_T	(1, 3592)	= 261.438	$p < .001$
F_{ST}	(3, 3592)	= 23.843	$p < .001$

P6			
Response times:			
F_S	(3, 3256)	= 34.231	$p < .001$
F_C	(1, 3256)	= 31.522	$p < .001$
F_T	(1, 3256)	= 979.584	$p < .001$
F_{CS}	(3, 3256)	= 1.632	$p = .180$
F_{ST}	(3, 3256)	= 36.264	$p < .001$
F_{CT}	(1, 3256)	= 1.760	$p = .185$
F_{CST}	(3, 3256)	= 1.849	$p = .136$
Errors:			
χ^2_S	(3, N=3572)	= 3.591	$p = .309$
χ^2_C	(1, N=3572)	= 10.441	$p = .001$
χ^2_T	(1, N=3572)	= 5.464	$p = .019$
χ^2_{CS}	(3, N=3572)	= 4.440	$p = .218$
χ^2_{ST}	(3, N=3572)	= 6.888	$p = .076$
χ^2_{CT}	(1, N=3572)	= 3.253	$p = .071$
χ^2_{CST}	(3, N=3572)	= 9.723	$p = .021$
Response Accuracy in pID:			
χ^2_S	(3, N=3600)	= 60.616	$p < .001$
χ^2_T	(1, N=3600)	= 2.272	$p = .132$
χ^2_{ST}	(3, N=3600)	= 6.692	$p = .082$
Ratings on PAS:			
F_S	(3, 3592)	= 95.526	$p < .001$
F_T	(1, 3592)	= 164.817	$p < .001$
F_{ST}	(3, 3592)	= 16.242	$p < .001$

P7			
Response times:			
F_S	(3, 3357)	= 1.872	$p = .132$
F_C	(1, 3357)	= 168.747	$p < .001$
F_T	(1, 3357)	= 1273.619	$p < .001$
F_{CS}	(3, 3357)	= 0.495	$p = .686$
F_{ST}	(3, 3357)	= 0.659	$p = .577$
F_{CT}	(1, 3357)	= 23.316	$p < .001$
F_{CST}	(3, 3357)	= 6.646	$p < .001$
Errors:			
χ^2_S	(3, N=3594)	= 1.504	$p = .681$
χ^2_C	(1, N=3594)	= 46.040	$p < .001$
χ^2_T	(1, N=3594)	= 10.288	$p = .001$
χ^2_{CS}	(3, N=3594)	= 3.867	$p = .276$
χ^2_{ST}	(3, N=3594)	= 6.851	$p = .077$
χ^2_{CT}	(1, N=3594)	= 0.383	$p = .536$
χ^2_{CST}	(3, N=3594)	= 13.037	$p = .005$
Response Accuracy in pID:			
χ^2_S	(3, N=3600)	= 24.471	$p < .001$
χ^2_T	(1, N=3600)	= 15.634	$p < .001$
χ^2_{ST}	(3, N=3600)	= 9.029	$p = .029$
Ratings on PAS:			
F_S	(3, 3592)	= 220.262	$p < .001$
F_T	(1, 3592)	= 1827.489	$p < .001$
F_{ST}	(3, 3592)	= 50.827	$p < .001$

P8			
Response times:			
F_S	(3, 3415)	= 0.739	$p = .529$
F_C	(1, 3415)	= 39.876	$p < .001$
F_T	(1, 3415)	= 357.184	$p < .001$
F_{CS}	(3, 3415)	= 0.867	$p = .457$
F_{ST}	(3, 3415)	= 0.851	$p = .466$
F_{CT}	(1, 3415)	= 0.012	$p = .911$
F_{CST}	(3, 3415)	= 0.336	$p = .799$
Errors:			
χ^2_S	(3, N=3590)	= 6.856	$p = .077$
χ^2_C	(1, N=3590)	= 0.000	$p = .995$
χ^2_T	(1, N=3590)	= 73.790	$p = .001$
χ^2_{CS}	(3, N=3590)	= 2.790	$p = .425$
χ^2_{ST}	(3, N=3590)	= 9.432	$p = .024$
χ^2_{CT}	(1, N=3590)	= 0.000	$p = .994$
χ^2_{CST}	(3, N=3590)	= 5.677	$p = .128$
Response Accuracy in pID:			
χ^2_S	(3, N=3600)	= 1.048	$p = .790$
χ^2_T	(1, N=3600)	= 0.343	$p = .558$
χ^2_{ST}	(3, N=3600)	= 0.425	$p = .935$
Ratings on PAS:			
F_S	(3, 3592)	= 0.800	$p = .494$
F_T	(1, 3592)	= 243,045	$p < .001$
F_{ST}	(3, 3592)	= 0.906	$p = .437$

B: Results for individual participants in Experiment 2 (Part II)

Table B1 and Table B2 hold the test statistics and *p* values for the individual main effects and interactions reported in graphical form in Figure 28.

Table B1: Test statistics, degrees of freedom, and p values for the main effects and interactions reported in Figure 28. The large number of denominator degrees of freedom is determined by the number of trials per participant. Note that these analyses aim to generalize to new trials from the same participant rather than to new participants.

P1			
Response times:			
F_S	(3, 3461)	= 3.953	p = .008
F_C	(1, 3461)	= 103.898	p < .001
F_T	(1, 3461)	= 518.197	p < .001
F_{CS}	(3, 3461)	= 2.796	p = .039
F_{ST}	(3, 3461)	= 10.517	p < .001
F_{CT}	(1, 3461)	= 0.162	p = .687
F_{CST}	(3, 3461)	= 0.982	p = .400
Errors:			
χ^2_S	(3, N=3582)	= 4.438	p = .218
χ^2_C	(1, N=3582)	= 15.388	p < .001
χ^2_T	(1, N=3582)	= 59.293	p < .001
χ^2_{CS}	(3, N=3582)	= 1.647	p = .649
χ^2_{ST}	(3, N=3582)	= 6.602	p = .086
χ^2_{CT}	(1, N=3582)	= 4.011	p = .045
χ^2_{CST}	(3, N=3582)	= 1.606	p = .658
Response Accuracy in pID:			
χ^2_S	(3, N=3584)	= 12.962	p = .005
χ^2_T	(1, N=3584)	= 206.661	p < .001
χ^2_{ST}	(3, N=3584)	= 10.331	p = .016

P2			
Response times:			
F_S	(3, 3392)	= 2.140	p = .093
F_C	(1, 3392)	= 221.770	p < .001
F_T	(1, 3392)	= 171.702	p < .001
F_{CS}	(3, 3392)	= 9.755	p < .001
F_{ST}	(3, 3392)	= 0.875	p = .453
F_{CT}	(1, 3392)	= 0.031	p = .861
F_{CST}	(3, 3392)	= 0.789	p = .500
Errors:			
χ^2_S	(3, N=3583)	= 6.432	p = .092
χ^2_C	(1, N=3583)	= 29.110	p < .001
χ^2_T	(1, N=3583)	= 4.075	p = .044
χ^2_{CS}	(3, N=3583)	= 13.685	p = .003
χ^2_{ST}	(3, N=3583)	= 4.526	p = .210
χ^2_{CT}	(1, N=3583)	= 1.661	p = .197
χ^2_{CST}	(3, N=3583)	= 3.321	p = .345
Response Accuracy in pID:			
χ^2_S	(3, N=3584)	= 4.315	p = .229
χ^2_T	(1, N=3584)	= 155.259	p < .001
χ^2_{ST}	(3, N=3584)	= 8.496	p = .037

P3			
Response times:			
F_S	(3, 3427)	= 1.291	p = .276
F_C	(1, 3427)	= 50.435	p < .001
F_T	(1, 3427)	= 759.111	p < .001
F_{CS}	(3, 3427)	= 1.833	p = .139
F_{ST}	(3, 3427)	= 0.520	p = .668
F_{CT}	(1, 3427)	= 28.823	p < .001
F_{CST}	(3, 3427)	= 0.861	p = .461
Errors:			
χ^2_S	(3, N=3575)	= 2.768	p = .429
χ^2_C	(1, N=3575)	= 4.048	p = .044
χ^2_T	(1, N=3575)	= 31.473	p < .001
χ^2_{CS}	(3, N=3575)	= 10.961	p = .012
χ^2_{ST}	(3, N=3575)	= 2.160	p = .540
χ^2_{CT}	(1, N=3575)	= 1.291	p = .256
χ^2_{CST}	(3, N=3575)	= 2.478	p = .479
Response Accuracy in pID:			
χ^2_S	(3, N=3584)	= 97.064	p < .001
χ^2_T	(1, N=3584)	= 611.273	p < .001
χ^2_{ST}	(3, N=3584)	= 94.087	p < .001

P4			
Response times:			
F_S	(3, 3396)	= 26.017	p < .001
F_C	(1, 3396)	= 262.107	p < .001
F_T	(1, 3396)	= 1526.714	p < .001
F_{CS}	(3, 3396)	= 2.304	p = .075
F_{ST}	(3, 3396)	= 16.872	p < .001
F_{CT}	(1, 3396)	= 34.397	p < .001
F_{CST}	(3, 3396)	= 1.420	p = .235
Errors:			
χ^2_S	(3, N=3576)	= 2.953	p = .399
χ^2_C	(1, N=3576)	= 18.499	p < .001
χ^2_T	(1, N=3576)	= 0.016	p = .899
χ^2_{CS}	(3, N=3576)	= 2.483	p = .478
χ^2_{ST}	(3, N=3576)	= 0.156	p = .984
χ^2_{CT}	(1, N=3576)	= 0.109	p = .742
χ^2_{CST}	(3, N=3576)	= 1.199	p = .753
Response Accuracy in pID:			
χ^2_S	(3, N=3584)	= 10.635	p = .014
χ^2_T	(1, N=3584)	= 67.220	p < .001
χ^2_{ST}	(3, N=3584)	= 10.463	p = .015

Table B2: Test statistics, degrees of freedom, and p values for the main effects and interactions reported in Figure 28. The large number of denominator degrees of freedom is determined by the number of trials per participant. Note that these analyses aim to generalize to new trials from the same participant rather than to new participants.

P5

Response times:			
F_S	(3, 3465)	= 0.241	p = .868
F_C	(1, 3465)	= 11.110	p = .001
F_T	(1, 3465)	= 788.574	p < .001
F_{CS}	(3, 3465)	= 2.673	p = .046
F_{ST}	(3, 3465)	= 0.788	p = .501
F_{CT}	(1, 3465)	= 0.220	p = .639
F_{CST}	(3, 3465)	= 5.558	p = .001
Errors:			
χ^2_S	(3, N=3578)	= 11.271	p = .010
χ^2_C	(1, N=3578)	= 0.807	p = .369
χ^2_T	(1, N=3578)	= 15.699	p < .001
χ^2_{CS}	(3, N=3578)	= 5.107	p = .164
χ^2_{ST}	(3, N=3578)	= 5.360	p = .147
χ^2_{CT}	(1, N=3578)	= 1.535	p = .215
χ^2_{CST}	(3, N=3578)	= 5.509	p = .138
Response Accuracy in pID:			
χ^2_S	(3, N=3584)	= 29.170	p < .001
χ^2_T	(1, N=3584)	= 24.027	p < .001
χ^2_{ST}	(3, N=3584)	= 1.696	p = .638

P6

Response times:			
F_S	(3, 3344)	= 1.678	p = .170
F_C	(1, 3344)	= 191.854	p < .001
F_T	(1, 3344)	= 142.569	p < .001
F_{CS}	(3, 3344)	= 9.227	p < .001
F_{ST}	(3, 3344)	= 1.804	p = .144
F_{CT}	(1, 3344)	= 53.833	p < .001
F_{CST}	(3, 3344)	= 2.694	p = .045
Errors:			
χ^2_S	(3, N=3584)	= 8.433	p = .038
χ^2_C	(1, N=3584)	= 20.560	p < .001
χ^2_T	(1, N=3584)	= 0.155	p = .694
χ^2_{CS}	(3, N=3584)	= 18.369	p < .001
χ^2_{ST}	(3, N=3584)	= 2.778	p = .427
χ^2_{CT}	(1, N=3584)	= 14.989	p < .001
χ^2_{CST}	(3, N=3584)	= 2.160	p = .540
Response Accuracy in pID:			
χ^2_S	(3, N=3584)	= 62.129	p < .001
χ^2_T	(1, N=3584)	= 6.017	p = .014
χ^2_{ST}	(3, N=3584)	= 6.190	p = .103

P7

Response times:			
F_S	(3, 3410)	= 1.548	p = .200
F_C	(1, 3410)	= 5.134	p = .024
F_T	(1, 3410)	= 662.776	p < .001
F_{CS}	(3, 3410)	= 3.548	p = .014
F_{ST}	(3, 3410)	= 4.974	p = .002
F_{CT}	(1, 3410)	= 3.288	p = .070
F_{CST}	(3, 3410)	= 0.421	p = .738
Errors:			
χ^2_S	(3, N=3580)	= 0.971	p = .808
χ^2_C	(1, N=3580)	= 0.006	p = .939
χ^2_T	(1, N=3580)	= 23.944	p < .001
χ^2_{CS}	(3, N=3580)	= 6.478	p = .091
χ^2_{ST}	(3, N=3580)	= 2.780	p = .427
χ^2_{CT}	(1, N=3580)	= 3.885	p = .049
χ^2_{CST}	(3, N=3580)	= 2.366	p = .500
Response Accuracy in pID:			
χ^2_S	(3, N=3584)	= 310.401	p < .001
χ^2_T	(1, N=3584)	= 21.568	p < .001
χ^2_{ST}	(3, N=3584)	= 9.352	p = .025

P8

Response times:			
F_S	(3, 3366)	= 0.850	p = .467
F_C	(1, 3366)	= 422.049	p < .001
F_T	(1, 3366)	= 703.736	p < .001
F_{CS}	(3, 3366)	= 7.389	p < .001
F_{ST}	(3, 3366)	= 0.953	p = .414
F_{CT}	(1, 3366)	= 158.951	p < .001
F_{CST}	(3, 3366)	= 3.441	p = .016
Errors:			
χ^2_S	(3, N=3581)	= 1.837	p = .607
χ^2_C	(1, N=3581)	= 2.770	p = .096
χ^2_T	(1, N=3581)	= 11.340	p = .001
χ^2_{CS}	(3, N=3581)	= 2.436	p = .487
χ^2_{ST}	(3, N=3581)	= 1.139	p = .768
χ^2_{CT}	(1, N=3581)	= 0.735	p = .391
χ^2_{CST}	(3, N=3581)	= 10.481	p = .015
Response Accuracy in pID:			
χ^2_S	(3, N=3584)	= 95.535	p < .001
χ^2_T	(1, N=3584)	= 0.34	p = .853
χ^2_{ST}	(3, N=3584)	= 1.021	p = .796

C: Results for individual participants in Experiment 3 (Part II)

Table C1 and Table C2 hold the test statistics and *p* values for the individual main effects and interactions reported in graphical form in Figure 31.

Table C1: Test statistics, degrees of freedom, and p values for the main effects and interactions reported in Figure 31. The large number of denominator degrees of freedom is determined by the number of trials per participant. Note that these analyses aim to generalize to new trials from the same participant rather than to new participants.

P1			
Response times:			
F_{S}	(3, 3200)	= 2.533	p = .055
F_{C}	(1, 3200)	= 11.419	p = .001
F_{T}	(1, 3200)	= 530.351	p < .001
F_{CS}	(3, 3200)	= 1.347	p = .257
F_{ST}	(3, 3200)	= 1.472	p = .220
F_{CT}	(1, 3200)	= 0.093	p = .760
F_{CST}	(3, 3200)	= 0.987	p = .398
Errors:			
χ^2_{S}	(3, N=3349)	= 6.821	p = .078
χ^2_{C}	(1, N=3349)	= 0.266	p = .606
χ^2_{T}	(1, N=3349)	= 7.610	p = .006
χ^2_{CS}	(3, N=3349)	= 4.479	p = .214
χ^2_{ST}	(3, N=3349)	= 3.627	p = .305
χ^2_{CT}	(1, N=3349)	= 0.390	p = .532
χ^2_{CST}	(3, N=3349)	= 2.039	p = .564
Response Accuracy in pID:			
χ^2_{S}	(3, N=3360)	= 7.465	p = .058
χ^2_{T}	(1, N=3360)	= 203.095	p < .001
χ^2_{ST}	(3, N=3360)	= 9.030	p = .029

P2			
Response times:			
F_{S}	(3, 3297)	= 0.630	p = .596
F_{C}	(1, 3297)	= 0.248	p = .619
F_{T}	(1, 3297)	= 1602.058	p < .001
F_{CS}	(3, 3297)	= 1.474	p = .219
F_{ST}	(3, 3297)	= 1.499	p = .213
F_{CT}	(1, 3297)	= 0.512	p = .474
F_{CST}	(3, 3297)	= 1.386	p = .245
Errors:			
χ^2_{S}	(3, N=3354)	= 1.654	p = .647
χ^2_{C}	(1, N=3354)	= 0.000	p = .995
χ^2_{T}	(1, N=3354)	= 13.679	p < .001
χ^2_{CS}	(3, N=3354)	= 4.962	p = .175
χ^2_{ST}	(3, N=3354)	= 5.758	p = .124
χ^2_{CT}	(1, N=3354)	= 0.000	p = .992
χ^2_{CST}	(3, N=3354)	= 3.844	p = .279
Response Accuracy in pID:			
χ^2_{S}	(3, N=3360)	= 1.860	p = .602
χ^2_{T}	(1, N=3360)	= 1.883	p = .170
χ^2_{ST}	(3, N=3360)	= 8.777	p = .032

P3			
Response times:			
F_{S}	(3, 3170)	= 2.279	p = .077
F_{C}	(1, 3170)	= 1.115	p = .283
F_{T}	(1, 3170)	= 498.424	p < .001
F_{CS}	(3, 3170)	= 2.305	p = .075
F_{ST}	(3, 3170)	= 0.577	p = .630
F_{CT}	(1, 3170)	= 1.204	p = .273
F_{CST}	(3, 3170)	= 0.060	p = .981
Errors:			
χ^2_{S}	(3, N=3360)	= 11.000	p = .012
χ^2_{C}	(1, N=3360)	= 3.069	p = .080
χ^2_{T}	(1, N=3360)	= 30.881	p < .001
χ^2_{CS}	(3, N=3360)	= 5.863	p = .118
χ^2_{ST}	(3, N=3360)	= 3.587	p = .310
χ^2_{CT}	(1, N=3360)	= 1.786	p = .181
χ^2_{CST}	(3, N=3360)	= 1.150	p = .765
Response Accuracy in pID:			
χ^2_{S}	(3, N=3360)	= 2.383	p = .497
χ^2_{T}	(1, N=3360)	= 5.306	p = .021
χ^2_{ST}	(3, N=3360)	= 3.920	p = .270

P4			
Response times:			
F_{S}	(3, 3227)	= 1.034	p = .376
F_{C}	(1, 3227)	= 0.119	p = .730
F_{T}	(1, 3227)	= 487.395	p < .001
F_{CS}	(3, 3227)	= 0.379	p = .768
F_{ST}	(3, 3227)	= 1.457	p = .224
F_{CT}	(1, 3227)	= 0.018	p = .893
F_{CST}	(3, 3227)	= 0.058	p = .982
Errors:			
χ^2_{S}	(3, N=3353)	= 3.529	p = .317
χ^2_{C}	(1, N=3353)	= 7.053	p = .008
χ^2_{T}	(1, N=3353)	= 78.697	p < .001
χ^2_{CS}	(3, N=3353)	= 2.178	p = .536
χ^2_{ST}	(3, N=3353)	= 5.962	p = .113
χ^2_{CT}	(1, N=3353)	= 3.906	p = .048
χ^2_{CST}	(3, N=3353)	= 3.266	p = .352
Response Accuracy in pID:			
χ^2_{S}	(3, N=3360)	= 0.674	p = .879
χ^2_{T}	(1, N=3360)	= 0.896	p = .344
χ^2_{ST}	(3, N=3360)	= 0.717	p = .869

Table C2: Test statistics, degrees of freedom, and p values for the main effects and interactions reported in Figure 31. The large number of denominator degrees of freedom is determined by the number of trials per participant. Note that these analyses aim to generalize to new trials from the same participant rather than to new participants.

P5				**P6**				**P7**				**P8**			
Response times:				Response times:				Response times:				Response times:			
F_S	(3, 3231)	= 1.346	p = .258	F_S	(3, 3218)	= 2.255	p = .080	F_S	(3, 3206)	= 1.348	p = .257	F_S	(3, 3173)	= 3.067	p = .027
F_C	(1, 3231)	= 10.905	p = .001	F_C	(1, 3218)	= 3.665	p = .056	F_C	(1, 3206)	= 32.558	p < .001	F_C	(1, 3173)	= 10.717	p = .001
F_T	(1, 3231)	= 628.150	p < .001	F_T	(1, 3218)	= 1648.852	p < .001	F_T	(1, 3206)	= 639.936	p < .001	F_T	(1, 3173)	= 1076.401	p < .001
F_{CS}	(3, 3231)	= 0.864	p = .459	F_{CS}	(3, 3218)	= 0.808	p = .489	F_{CS}	(3, 3206)	= 5.012	p = .002	F_{CS}	(3, 3173)	= 1.630	p = .180
F_{ST}	(3, 3231)	= 2.860	p = .036	F_{ST}	(3, 3218)	= 0.084	p = .696	F_{ST}	(3, 3206)	= 0.288	p = .834	F_{ST}	(3, 3173)	= 3.014	p = .029
F_{CT}	(1, 3231)	= 5.238	p = .022	F_{CT}	(1, 3218)	= 6.538	p = .011	F_{CT}	(1, 3206)	= 0.456	p = .499	F_{CT}	(1, 3173)	= 4.820	p = .028
F_{CST}	(3, 3231)	= 1.457	p = .224	F_{CST}	(3, 3218)	= 0.161	p = .923	F_{CST}	(3, 3206)	= 0.356	p = .785	F_{CST}	(3, 3173)	= 0.107	p = .956
Errors:				Errors:				Errors:				Errors:			
χ^2_S	(3, N=3352)	= 5.397	p = .145	χ^2_S	(3, N=3355)	= 3.149	p = .369	χ^2_S	(3, N=3356)	= 8.219	p = .042	χ^2_S	(3, N=3353)	= 1.522	p = .677
χ^2_C	(1, N=3352)	= 0.007	p = .932	χ^2_C	(1, N=3355)	= 15.522	p < .001	χ^2_C	(1, N=3356)	= 1.440	p = .230	χ^2_C	(1, N=3353)	= 3.662	p = .056
χ^2_T	(1, N=3352)	= 12.177	p < .001	χ^2_T	(1, N=3355)	= 0.145	p = .703	χ^2_T	(1, N=3356)	= 0.692	p = .405	χ^2_T	(1, N=3353)	= 0.883	p = .347
χ^2_{CS}	(3, N=3352)	= 19.408	p < .001	χ^2_{CS}	(3, N=3355)	= 0.325	p = .955	χ^2_{CS}	(3, N=3356)	= 9.293	p = .026	χ^2_{CS}	(3, N=3353)	= 2.942	p = .401
χ^2_{ST}	(3, N=3352)	= 3.301	p = .348	χ^2_{ST}	(3, N=3355)	= 13.305	p = .004	χ^2_{ST}	(3, N=3356)	= 7.098	p = .0.69	χ^2_{ST}	(3, N=3353)	= 3.482	p = .323
χ^2_{CT}	(1, N=3352)	= 0.775	p = .379	χ^2_{CT}	(1, N=3355)	= 9.843	p = .002	χ^2_{CT}	(1, N=3356)	= 3.988	p = .046	χ^2_{CT}	(1, N=3353)	= 1.994	p = .158
χ^2_{CST}	(3, N=3352)	= 1.717	p = .633	χ^2_{CST}	(3, N=3355)	= 9.515	p = .023	χ^2_{CST}	(3, N=3356)	= 3.637	p = .303	χ^2_{CST}	(3, N=3353)	= 12.013	p = .007
Response Accuracy in pID:				Response Accuracy in pID:				Response Accuracy in pID:				Response Accuracy in pID:			
χ^2_S	(3, N=3360)	= 7.676	p = .053	χ^2_S	(3, N=3360)	= 3.637	p = .303	χ^2_S	(3, N=3360)	= 51.314	p < .001	χ^2_S	(3, N=3360)	= 2.310	p = .511
χ^2_T	(1, N=3360)	= 24.103	p < .001	χ^2_T	(1, N=3360)	= 0.067	p = .796	χ^2_T	(1, N=3360)	= 17.140	p < .001	χ^2_T	(1, N=3360)	= 2.752	p = .097
χ^2_{ST}	(3, N=3360)	= 1.199	p = .753	χ^2_{ST}	(3, N=3360)	= 2.494	p = .476	χ^2_{ST}	(3, N=3360)	= 74.545	p < .001	χ^2_{ST}	(3, N=3360)	= 3.016	p = .389

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List of Abbreviations

APA	American Psychological Association
ANOVA	Analysis of variance
BCS	Boundary Contour System
c	Conscious information
cd/m^2	Unit of Luminance
cm	Centimeter
c_{max}	Maximum contrast
c_{min}	Minimum contrast
con	Consistent
D	Direct measure
d’	Sensitivity index
DPS	Direct Parameter Specification
EEG	Electroencephalography
ERP	Event-related potential
FEF	Frontal eye field
FGM	Figure-ground modulation
fMRI	Functional magnetic resonance imagine
HVAs	Higher visual area(s)
HZ	Hertz
I	Indirect measure
incon	Inconsistent
IT	Inferior temporal
LRP	Lateralized readiness potential
M(s)	Masking function
MCF(s)	Mask-contrast function
MEG	Magnetoencephalography
mID	Mask identification
MRI	Magnetic resonance image
ms	Milliseconds
MT	Middle temporal area
N	Sample size

n	Quantity
P(s)	Priming function
PAS	Perceptual Awareness Scale
PDW	Post-decision wagering
pID	Prime identification
PR	Perceptual Retouch
r	Repeated measure per cell and subject
RECOD	Retino-cortical dynamics
RT	Response time
s	Standard deviation
SD	Standard deviation
SOA	Stimulus onset asynchrony
TUK	Technische Universität Kaiserslautern
TMS	Transcranial magnetic stimulation
u	Unconscious information
V1, V2, V4	Regions of the cortex

6. Academic career

since 06/2014	Doctoral student and research assistant at the working group of Prof. Dr. Thomas Schmidt, University of Kaiserslautern (TUK)
2011 – 04/2014	Master of Education for teaching at high schools at the TUK Title of the thesis: *Die SPD als Volkspartei: Rosarote Utopie? Eine Analyse des „(Miss-)ErVolksparteienkonzepts" der Sozialdemokratischen Partei Deutschlands*
2008 – 09/2011	Bachelor of Education for teaching at high schools at the TUK Title of the thesis: *Informationsverarbeitung von phobischen Bildern bei Spinnenängstlichen: eine Prior-Entry Studie*

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