Individual differences in subjective experience and objective performance in metacontrast masking

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When participants discriminate stimuli that are masked by a following stimulus via metacontrast masking, stable individually different masking functions have been found despite identical stimulation conditions. In the present study, in one group of observers objective performance increased with increasing target-mask stimulus onset asynchrony (SOA), whereas in another group performance decreased with increasing SOA. In addition, a group of overachievers showed ceiling effects whereas a group of underachievers hardly exceeded chance levels of performance irrespective of SOA. The differences between observers' objective measures of performance correspond to differences in participants' phenomenological reports of subjective experience. This indicates that participants differ in their access to specific perceptual cues that they use spontaneously to solve the task. When we instructed participants to use only one specific cue, the instructed cue determined participants' objective performance considerably in two experiments. Nevertheless, masking functions remained similar with and without the cued instruction, and the effect of cues depended on the initial masking function of individuals. Findings suggest that individuals with different masking functions differ also in terms of phenomenology, used cues, and response strategy. The relation between subjective experience, reported usage of perceptual cues, and objective performance in the metacontrast masking task deserves further investigation.

Keywords: metacontrast masking, phenomenology, subjective data, individual differences, consciousness


Introduction

Backward masking has been extensively used in studies on visual perception to limit the sensory input to the visual system and to examine stimulation parameters that determine participants’ performance in perceptual tasks (e.g., Bachmann, 1984, 1994; Breitmeyer & Ögmen, 2006; Turvey, 1973). In addition, backward masking has been applied as a ubiquitous tool in priming studies to render stimuli invisible and to investigate the effect of unconscious stimuli on information processing and behavior (e.g., Eimer & Schlaghecken, 1998; Fehr & Raab, 1962; Mattler, 2003, 2005, 2006; Neumann & Klöt, 1994; Schmidt, 2000, 2002; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003).

In these literatures, individual differences have not become a major issue, despite the periodical suggestion to consider individual differences in experimental psychology (Albrecht & Mattler, 2010; Cohen, 1994; Cronbach, 1957; Underwood, 1975). Traditionally research on visual perception focuses on general principles of perception that apply to the majority of participants. Due to the neural plasticity in the visual system, however, it is conceivable that differences in individuals’ perceptual experience are potentially capable of modifying observers’ perceptual system, which could result in stable individual differences in performing specific tasks. In addition to differences in the perceptual experience, stable individual differences might also arise from specific predispositions, which render observers differentially efficient in stimulus processing at certain levels of the visual system. This view is consistent with current theories of perceptual learning that assume multiple potential levels in the visual system at which perceptual learning can take place (Yotsumoto & Watanabe, 2008). Individual performance differences have also been predicted by ecologically motivated accounts of perceptual learning, which assume that participants can choose between different informational variables or perceptual cues to perform a task (e.g., Jacobs, Runeson, & Michaels, 2001; Runeson & Andersson, 2007; Withagen & van Wermeskerken, 2009). In this perspective, the environment provides the visual system with many different informational variables. For a given task, only a subset of the variables is specific, i.e., only some variables serve as reliable perceptual cues to solve the task. In
depth perception, for example, several cues provide the system with information about the depth of objects (e.g., relative height, texture, motion parallax). The visual system combines these cues to form a coherent experience of depth. However, optimal cue weighting is not the same in all circumstances. In a given situation, however, the visual system is capable of determining the cue combination that is most useful for the task at hand (e.g., Jacobs, 2002, Jacobs et al., 2001).

In a previous study, we reported qualitative individual differences in metacontrast masking, which were enhanced by perceptual learning (Albrecht, Klapötke & Mattler, 2010). Participants performed a stimulus discrimination task in a metacontrast masking paradigm with varying stimulus onset asynchronies (SOAs). Participants clustered into one of two groups based on their individual masking functions: In one group, discrimination performance increased with increasing SOA (type-A masking functions), and in the other group, discrimination performance decreased with increasing SOA (type-B masking functions). Individual masking functions became more specific with participants’ practice in the discrimination task and functions reached a stable time course that remained largely unchanged in follow-up measures 4 to 23 weeks later. These stable differences in objective discrimination performance among participants raise the question of whether participants’ phenomenological experience of the stimuli differs too. This view is consistent with a report of Maksimov, Murd, and Bachmann (2011) that only participants who exhibited type-A masking functions in the objective task stated perceiving a rotational movement in the target-mask sequence. Alternatively, participants might not differ in their subjective experience but use individually different strategies to perform the task. For instance, participants might have based their response on a voluntarily selected aspect of the stimulus sequence, as noted by Bachmann (2010) in a comment on our previous study.

The use of different stimulus attributes or different informational variables has been captured in the masking literature by the concept of criterion content, which refers to the psychological dimension or perceptual cue on which participants base their judgment (e.g., Kahneman, 1968; Ventura, 1980). For instance, in the domain of metacontrast masking, Lachter and Durgin (1999), and Lachter, Durgin, and Washington (2000) proposed that judgments which are based on early perceptual information (i.e., when participants are forced to respond quickly) result in better performance at intermediate SOAs of about 50 milliseconds than judgments which are based on late perceptual information (i.e., when participants were forced to respond more slowly).

To shed more light on this issue, we examined whether participants with different objective performance nonetheless subjectively experience the stimulation in the same way. To this end, we measured participants’ masking functions and asked them in phenomenological experiments to report how they experience the stimuli. We think such an approach might contribute to link masking effects to research on the generation of conscious experience.

### Phenomenology of target perception

In the literature, it is undisputed that the phenomenological percepts produced by masking can differ between individual participants. However, only a few detailed investigations of the phenomenological aspects of masking have been reported. In metacontrast masking the most prominent phenomenological effect that has been reported is a reduction of the perceived target contrast due to the presentation of the mask (Breitmeyer & Ögmen, 2006). In consequence, researchers have frequently used a brightness-rating task to measure target perception in various masking conditions (e.g., Weissstein, Jurkens, & Onderisi, 1970; Lachter & Durgin, 1999; Breitmeyer & Horman, 1981).

One of the rare reports on phenomenological percepts in metacontrast masking dates back 75 years. Using a black target disc followed by a black masking annulus on white background, Werner (1935) observed that the target seems to disappear with optimal masking conditions, which differed between participants. In addition, Werner reported on page 41 that “by voluntarily evoking a certain attitude in observation” the target “can be made to vanish” even with suboptimal masking conditions. Werner observed that the masking procedure does not produce the same phenomenological experience on every trial: he reported that the target disappeared on 80% of the trials, it was seen as a somewhat gray shadow on 13% of the trials, and the target appeared to be brighter than the background on 7% of the trials. Werner speculated that the latter effect might result from a successive contrast or afterimage effect. Werner (1935) varied the fit between the outer contour of the target and the inner contour of the mask and observed that the phenomenological experience changed regularly among three percepts: First, when target and mask contours were dissimilar, the target was clearly visible with dark contours and a bright inner part. Second, when target and mask contours were similar, participants perceived the outer contour of the target as part of the inner contour of the mask, and the inner part of the target appeared in a light gray. Third, when the target fitted exactly in the inner contour of the mask, participants ascribed the contours of the target to the mask and the inner part of the target did not differ from the...
background. Percepts changed between these three types in every participant when target-mask similarity was increased. On the other hand, however, Werner (1935) also observed that the degree of similarity required to change participants’ percepts from one stage to the other was individually different.

Similar to Werner’s notion of afterimages that appeared brighter than the background, a brightness reversal of the target relative to its immediate surrounding background has been reported for metacontrast masking (Stewart, Purcell, & Pinkham, 2011; Heckenmueller & Dember, 1965) as well as for other types of masking (Brussell, Stober, & Favreau, 1978; Purcell & Dember, 1968; Sperling, 1960). In a recent study Stewart and colleagues (2011) found that this brightness reversal predominantly emerged at a SOA of 20 milliseconds.

The phenomenology and the basic paradigm of metacontrast masking has been related to apparent motion. This phenomenon can be generated by two alternating flashed lights at two different spatial positions. Depending on the spatial and temporal lag between the stimuli, a smooth movement can be seen if a single light stimulus moves continuously along a straight line between the two stimulus positions (e.g., Wertheimer, 1912). Several studies that investigated the relation of metacontrast and apparent motion mentioned similarities between these two paradigms but there has been no convincing argument for a common mechanism in both of these paradigms (e.g., Breitmeyer, Battaglia, & Weber, 1976; Breitmeyer & Horn, 1981; Kahneman, 1967; Wertheimer, 1912; for a review see Breitmeyer & Ögmen, 2006). One phenomenological similarity between the two paradigms consists in the finding that the percept of the second stimulus seems to eliminate the percept of the previous stimulus. In a study of apparent motion, Wertheimer (1912) used stroboscopic motion and observed that the second stimulus eliminates the percept of the preceding stimulus. Schumann (1899, as cited in Wertheimer, 1912) reported that a rapid succession of a horizontal bar followed by a vertical bar leads to the experience of a motion illusion of only one rotating bar. This experience also includes an extinction of the percept of the immediately preceding stimulus. In metacontrast masking, a similar dissociation between a motion percept and the elimination of the percept of the preceding stimulus has been observed in more recent studies. Ansorge, Becker, and Breitmeyer (2009) and Ansorge, Breitmeyer, and Becker (2007) found for certain conditions that participants could not report the shape of a target stimulus, but they were nonetheless able to detect rotation (on incongruent trials) in the stimulus sequence. Taken together, the literature suggests that metacontrast masking can produce specific perceptual experiences including aftereffects and apparent motion. The exact phenomenological experience of the stimulus sequence seems to be a function of individual differences and stimulation parameters including stimulus energy and SOA (Wertheimer, 1912; Werner, 1935).

**Overview**

The present study attempted to shed more light on the issue of why individual participants produce qualitatively different masking functions when stimulation parameters are identical (Albrecht, Klápötke et al., 2010). Based on the cited literature, our own phenomenological experiences, and participants’ reports (Albrecht & Mattler, 2010; Albrecht, Klápötke et al., 2010), we reasoned that participants might produce different masking functions because they recruit different kinds of perceptual cues or weight those perceptual cues differently. In particular, we hypothesized that the crucial cues that potentially emerge in the specific stimulus sequence used in our experiments are (a) a kind of bright afterimage or brightness reversal of the target that results from target mask interactions at short SOA (Stewart et al., 2011; Werner, 1935) and (b) motion cues that result from the experience of apparent rotational motion at longer SOAs, especially on trials where target and mask shapes are incongruent (see also Ansorge et al., 2007; 2009; Maksimov et al., 2011). If these two types of cues provide reliable information about the shape of the target stimulus only at specific SOAs, individually different masking functions could result. Namely, if motion cues allow reliable target discrimination only at long SOAs and if afterimages allow reliable target discrimination only at SOAs, type-A masking functions should result when participants mainly rely on motion cues, and type-B masking functions should result when participants mainly rely on afterimages. In consequence, participants who fail to recruit either cue should show flat masking functions near chance level and participants who are able to recruit both cues should show flat masking functions on a very high performance level. Beyond this, we wondered whether participants can voluntarily choose to use one or the other cue. Alternatively, participants might perceive the stimulus sequence in such a way that they have no choice but to use the cue that is provided by their visual system (Albrecht & Mattler, 2010; see Bachmann, 2010, for suggestions of similar experiments).

A group of 30 participants was examined in three experiments and an additional group of 31 participants was examined in a fourth experiment. **Experiment 1** was designed to replicate our previous finding that different groups of observers can be distinguished by their masking functions. In **Experiment 2**, we aimed to examine the phenomenological experiences of observers in more detail by asking them to report their
experiences. An analysis of these reports should reveal the informational variables participants use to discriminate the target shapes, and whether participants report the same phenomenological experiences when they watch the stimulus sequence. Experiments 3 and 4 were designed to examine whether participants can use explicitly given cues irrespective of their prior masking function and switch the criterion content according to the given cue. To anticipate our results, participants reported different phenomenological experiences, which correspond to afterimages and motion aftereffects, and they exhibited difficulties to use cues that they have not used before.

In our previous study (Albrecht, Klapötke et al. 2010), we classified participants according to the slope of their individual masking function without taking into account the absolute level of masking. This distinction was based on the assumption that some unknown differences between participants lead to different temporal dynamics in masking. However, it has to be mentioned that participants could be distinguished in various alternative ways. For instance, one reviewer of this paper suggested that participants should be distinguished according to their performance at single SOAs. Our reading of the metacontrast literature suggests, however, that it is widely assumed that the masking function reflects the time course of processes that cause the masking effect, respective of the perception of the target. In consequence, the masking function has been considered more important than the absolute level of performance at specific SOAs in this literature. This is also reflected in the distinction of type-A and type-B masking functions (e.g., Kolers, 1962; Weisstein, 1966; Bachmann, 1994; Ishikawa, Shimegi, & Sato, 2006; Breitmeyer, Kafaligönlü, Ögmen, Mardon, Todd, & Ziegler, 2006). To link our findings to this literature, it seems reasonable to stay with this traditional distinction and to focus on differences between participants in the temporal characteristics of masking rather than on performance differences at single SOAs. Nevertheless, we chose a more data driven approach in the present study and based the classification on both the absolute performance levels and on information about the slope of masking functions by entering the $d'$ values at the 24 milliseconds SOA and the 72 milliseconds SOA.

**Experiment 1**

**Methods**

**Participants**

Thirty (26 female, 4 male) students of Georg-August University Göttingen participated in two sessions which lasted for approximately one hour each. Their ages varied between 19 and 40 years (mean 23 years). All had normal or corrected to normal vision and received partial course credit or monetary reward. All gave their informed consent.

**Task**

Participants were instructed to respond as accurately as possible and without speed stress to the shape of the target stimulus (square or diamond) with a left or right hand response.

**Stimuli**

The target stimuli were small filled squares and diamonds subtending 1.5° of visual angle and the masks were larger framing stimuli with square- and diamond-shaped outer contours subtending 2.6° of visual angle. The outer contours of the targets fitted neatly into the inner contours of the masks leaving a space of one pixel, which corresponds to 0.02° of visual angle (Figure 1a and b). All stimuli were black (0.03 cd/m²) on a light grey background (72.3 cd/m²) in the center of the screen with durations of 24 milliseconds and 108
millisecond for targets and masks, respectively. Targets preceded the mask with an SOA of 24, 36, 48, 60, 72, or 84 milliseconds in Session 1 and with a SOA of 24 or 72 milliseconds in Session 2. In half of the trials the target and mask stimuli were congruent (both stimuli were squares or diamonds). In the other half of the trials, the target and mask stimuli were incongruent (one stimulus a square and the other a diamond). Auditory feedback (1000 hertz, 100 milliseconds) was given after each erroneous response.

Procedure

All experimental procedures described in this article are in accordance with the Declaration of Helsinki. Each trial started with a fixation cross for 750 milliseconds followed by the target and the mask (Figure 1a). The inter-trial interval varied between 800 milliseconds and 1850 milliseconds following a quasi-exponential distribution. Participants were instructed to keep their gaze on the fixation cross throughout the trial and to respond as accurately as possible to the shape of the target stimulus without paying attention to the masking stimulus. Participants pressed the left STRG-button of the computer keyboard upon seeing a square and the right STRG-button when seeing a diamond. Participants had to respond within 3 seconds after mask onset.

Design

Each session was run on a separate day and comprised 13 blocks of 48 trials each. The first block of each session was considered warm-up and discarded from further analysis. Independent variables congruency (congruent vs. incongruent) and SOA (24, 36, 48, 60, 72, and 84 milliseconds) were varied pseudorandomly within each block so that each of the 12 combinations was repeated four times in each block and 48 times in each session. In Session 2, only two pseudorandomly varying SOAs with 24 milliseconds and 72 milliseconds were employed.

Data Analysis

Discrimination performance for each participant and SOA was assessed by signal detection analyses resulting in measures of sensitivity and response bias. Measures of sensitivity, $d'$, were calculated separately for each masking stimulus and averaged across type of masking stimuli (Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2004). Measures of response bias were calculated for each participant and SOA in terms of criterion index $C$ separately for each mask (see Albrecht & Mattler, in press).

Results

Performance measures in terms of $d'$ of Session 1 are displayed in Figure 2a through e. Visual inspection of the individual masking functions reveals substantial interindividual variability (Figure 2a through d). Six observers’ performance was poor with short SOA but improved with increasing SOA (“type-A observers,” Figure 2a). Ten participants’ performance decreased with increasing SOA and reached poor performance with long SOA (“type-B observers,” Figure 2b). Ten participants’ performance remained at poor levels across all SOAs (Figure 2c). For convenience, we will call this group “underachievers” in the following. Four participants performed at high levels across all SOAs (Figure 2d). We will call this group “overachievers” in the following. These four groups of individual masking functions resulted from a four-cluster solution of a $k$-means cluster analysis based on the discrimination performance ($d'$) at the 24 milliseconds SOA and the 72 milliseconds SOA of Session 1 (Calinski-Harabasz-Criterion $VRC = 38.8$, Calinski & Harabasz, 1974). Solutions with less or more than four clusters lead to a severe drop in the Calinski-Harabasz-Criterion ($VRC < 32.0$ and $VRC < 10.0$, respectively). Figure 2e shows the average masking function for each of the four groups.

Measures of $d'$ of Session 2 corroborated the data pattern of Session 1 (Figure 2f). When performance with 24 milliseconds SOA was compared to the performance with 72 milliseconds SOA, masking functions of type-A observers increased significantly with SOA ($t[5] = 9.68, p < 0.001$) whereas masking functions of type-B observers decreased significantly with increasing SOA ($t[9] = 9.38, p < 0.0001$). Masking functions of underachievers did not show a significant difference between long and short SOA ($t[9] = 1.9, p = 0.08$). Moreover, these participants did not perform significantly better than chance ($t[9] = 1.53, p = 0.16$). Performance of overachievers at 24 milliseconds SOA and 72 milliseconds SOA did not differ ($t[3] = 0.80, p = 0.48$).

Response criterion

Figure 3 shows signal detection’s response criterion $C$ for the four groups. In signal detection theory, positive values of $C$ reflect a conservative response bias while negative values of $C$ reflect a liberal response bias. In the present analysis, a conservative response bias means that participants predominantly respond “diamond,” whereas a liberal response bias means that participants predominantly respond “square.” A three-way ANOVA revealed a significant interaction of Type $\times$ Mask $\times$ SOA ($F[15, 130] = 3.02, p < 0.001$). Therefore, we conducted separate two-way ANOVAs
for each group of observers. Figure 3a shows that type-A observers' response was biased towards the outer shape of the mask at short SOAs and this bias decreased with increasing SOA. This was true for both sessions (Interaction Mask × SOA: $F[5, 25] = 6.72, p < 0.001$ and $F[1, 5] = 15.37, p = 0.01$, for Session 1 and Session 2, respectively). In addition, the main effect of SOA was significant in Session 1 but not in Session 2, and the main effect of mask was significant in Session 2 ($F[1, 5] = 8.43, p < 0.05$), but not in Session 1 ($F[1, 5] = 3.7, p > 0.11$). Figure 3b shows that there was no systematic response bias in type-B observers, neither in the first nor in the second session ($ps > 0.20$ and $p < 0.07$, respectively). Similarly, Figure 3c shows the absence of systematic response biases in “underachievers”: for Session 1 the main effect for SOA was
significant ($F[5, 45] = 2.85, p < 0.05$), but this effect was not corroborated in Session 2 ($F[1, 9] = 0.73, p = 0.41$). No other effects were significant in any session ($ps > 0.18$ and $ps > 0.34$ for Session 1 and Session 2, respectively). The “overachievers” (Figure 3d) showed a similar but less pronounced interaction than type-A observers which did not prove significant in any session ($F[5, 15] = 1.79, p = 0.18$ and $F[1, 3] = 2.66, p = 0.20$, for Session 1 and Session 2, respectively). The main effect of SOA was significant in both sessions ($F[5, 15] = 3.03, p < 0.05$, and $F[1, 3] = 18.9, p < 0.05$, for Session 1 and Session 2, respectively) and the main effect of mask was significant in Session 1 but not in Session 2 ($F[1, 3] = 37.8, p < 0.01$ and $F[1, 3] = 3.72, p = 0.15$, respectively).

**Discussion**

Experiment 1 replicated and extended findings from our previous study (Albrecht, Klapötke et al., 2010) which showed qualitative individual differences in the time course of target discrimination performance despite identical stimulation parameters. As in our previous study, masking functions of one group of observers increased with SOA and the functions of another group of observers decreased with increasing SOA. In addition, the present Experiment revealed two groups of individuals whose performance did not depend on SOA: “underachievers” who seem to be unable to discriminate the target stimuli above chance levels at any level of the examined SOAs and “overachievers” who perform well across the entire range of SOA. The poor performance of underachievers could result if these participants try to perform well but for various reasons they do not succeed at any level of SOA. This could be the consequence of participants’ lack of reliable access to the information, which participants of the other groups can use. Alternatively, underachievers might have access to the same information as the other participants, but they are unable to use these cues successfully. In addition, the poor performance of underachievers could be due to a lack of motivation or a failure of compliance which might have resulted because the frequently given error feedback was too discouraging for the participants of this group. As mentioned above, Lachter and Durgin (1999) reported that differences in response speed can lead to differences in discrimination performance. For the present findings, however, this explanation seems to be unlikely because groups did not differ in response speed ($F[3, 26] = 0.86, p = 0.47$) and the average response speed of our participants (707 milliseconds) was comparable to that of Lachter and Durgin (1999) delayed responding group.

Results response bias analyses replicated findings from an earlier study (Albrecht & Mattler, in press). Type-A participants showed a strong response bias towards the outer shape of the mask on short SOAs but not on long SOAs whereas the other observers did not show reliable response biases. This fits nicely to the finding that only type-A observers responded systematically to the shape of the mask when no target stimulus was presented (Albrecht & Mattler, in press). Therefore, we propose that type-A observers respond according to the following strategy: When they see rotational motion in the target-mask stimulus sequence, they report that the target was opposite to the mask. However, when they perceive no such rotational motion they report that the target had the same shape as the mask. This strategy leads to high levels of performance with long SOA probably because rotational motion cues are more reliable with long SOA (see Albrecht & Mattler, in press; Maksimov et al., 2011). The later assumption is supported by literature on apparent motion that shows that motion percepts occur only with specific spatial and temporal parameters (e.g., Wertheimer, 1912).

The findings of our experiment seem to depend on the fact that we used masks that were either congruent or incongruent to the shape of the primes. To examine the role of target-mask congruency one might think that separate analyses of congruent and incongruent trials might be the best way to go (see e.g., Maksimov et al., 2011). To illustrate this, we present percentage correct data for congruent and incongruent trials of Experiment 1 in Supplementary Figure S1. However, this approach departs crucially from traditional signal detection analysis because it is in danger of confounding measures of sensitivity with measures of response bias (see Albrecht & Mattler, in press; Macmillan & Creelman, 1991; Vorberg et al., 2004). To illustrate this problem, consider the case that an observer does not comply with task instructions to discriminate targets but rather responds to the shape of the mask. In this case, he or she would be correct on 50% of all trials. This corresponds to chance performance, which should be reflected in the results of the data analysis. However, if one regards only congruent trials, this observer would be perfectly correct. On incongruent trials, however, the observer would be incorrect on every trial (see type-A observers with short SOA in Supplementary Figure S1a). In other words, a distinction of congruent and incongruent trials would indicate substantial performance differences in target discrimination, which depend on congruency although the true sensitivity is zero in both conditions. Signal detection analysis is useful in resolving this confound by computing sensitivity measure $d'$ and response bias measure $C$ separately for each mask. This corresponds to the recommendation to keep conditions constant that are likely to affect response bias (see Macmillan & Creelman, 1991; Vorberg et al., 2004). The present data
exemplifies that this analysis uncovers the behavior of the above considered observer that the true sensitivity is zero and the response is driven by the shape of the mask (see Type A observers with short SOA in Figures 1a and 2a, and Supplementary Figure S1a). Finally, we wish to note that clustering the data of a sample produces results with severely limited generalizability because the result of a cluster analysis is a function of the number of clusters, the exact parameter on which clustering is based, and the specific random assembling of the sample. For instance, in Albrecht, Klapötke et al. (2010) we based clustering on the slope of the masking functions irrespective of performance levels at single SOAs. In the present study, we chose a more data driven approach and based clustering on the combination of absolute and relative levels of performance at the 24 and the 72 milliseconds SOA. When we cluster the present data on the slope of the masking functions, like before, slightly different groups result. Nonetheless, with both approaches we replicate a finding which has been observed by now with different random samples, namely that a group with type-A masking functions can be distinguished from a group with type-B masking functions (Albrecht, Klapötke et al., 2010; Albrecht & Mattler, in press; Maksimov et al., 2011). Importantly, however, our research aims to account for the phenomenon of stable interindividual differences in objective measures of target perception in the metacontrast masking paradigm. This does not necessarily require that individuals fall into a specific number of groups although our previous studies suggested two characteristically different groups of observers. Future research will show whether human observers in metacontrast masking are best conceived as individuals that are evenly dispersed across some kind of continuum or rather as members of characteristic groups. It is but one approach to examine whether type-A and type-B observers are also distinguished by other communalities that they share with the other members of their group.

**Experiment 2**

In Experiment 1, we replicated our earlier findings that participants with characteristically different masking functions can be distinguished. However, does this implicate that observers experience the same stimuli in different ways? In Experiment 2, we sought to (a) identify the perceptual cues in a metacontrast paradigm on a phenomenological basis and (b) discover whether the experience of these cues are related to the individual masking function exhibited in Experiment 1. Our own observations and reports of participants of previous experiments led to the prediction that type-A observers predominantly report motion percepts (see also Maksimov et al., 2011) and type-B observers predominantly report afterimages. There was no specific expectation regarding the reports of overachievers and underachievers. However, a detailed analysis of their reports of subjective experience promised answers to the questions of (a) whether underachievers have no access to the cues that the other groups use, (b) whether they experience the same percepts but do not know how to use cues successfully in this task, and (c) whether overachievers have superior access to both cues.

**Methods**

**Participants**

All 30 participants from Experiment 1 were tested in a one-hour session and received partial course credit or monetary reward.

**Task**

There were two different sections: the free report section and the question section. In both sections, participants were instructed to attend to the stimulus sequence presented on the screen. In the free report section, they were to describe freely what they saw on each trial in detail. Participants were told that they should not restrict their description to the shape of the target stimulus but rather to describe the entire percept as it unfolds in time. It is important to note that instructions did not refer to the concepts of motion or afterimages. In the question section, participants responded to a series of questions asked orally by the investigator (Table 1). In contrast to Experiment 1, instructions did not emphasize the accuracy of performance but the subjective experience of participants (see discussion below for possible effects of this instruction).

**Stimuli**

The Stimuli were the same as those in Experiment 1 except that SOA varied randomly between either 24 milliseconds or 72 milliseconds. Participants did not receive any feedback.

**Procedure**

The sequence of events in each trial was the same as in Experiment 1 with the following exceptions: After presentation of each stimulus sequence, the screen remained blank and the participants either freely described their percepts (free report section) or answered specific questions of the investigator who wrote the answers down (question section). After answering each trial, participants started the next trial.
1. Was the first stimulus a square or a diamond? (square/diamond)
2. How confident are you? (sure/unsure)
3. Did you see both stimuli as clear and distinct entities? (yes/no)
4. Did you perceive a light-gray or white stimulus or a shadow in the center of the screen, after the first and/or second stimulus has vanished already? (yes/no)
5. Did you use the shape of this light stimulus to answer Question 1? (yes/no)
6. Did you see something like motion, rotation or an enlargement in the stimulus sequence? (yes/no)
7. Did you use this percept to infer the answer of Question 1? (yes/no)

Table 1. Questions asked in the second part of Experiment 2. Questions that were conditional on 'yes'-responses to the superordinate question are printed in italics.

by pressing the space bar. The experiment consisted of four blocks with eight trials each. Each combination of target (square, diamond), mask (square, diamond), and SOA (24 milliseconds, 72 milliseconds) occurred once in every block. The free report section comprised the first two blocks and the question section comprised the last two blocks. The free report section preceded the question section for all participants so that every participant was naïve to the concepts of motion and afterimages in the free report part. In the question section, following an affirmative response, we continued to ask whether participants used this percept to determine the shape of the target stimulus.

Statistical analyses

Two independent and naïve raters classified each of the free reports according to whether they describe (a) a motion percept, (b) an afterimage percept, (c) both, or (d) neither. Raters were instructed to count a report as motion percept, if it contains a description of rotating or moving stimuli or an enlargement of a stimulus. An afterimage percept was operationalized as a report that contains a description of a shadow within the inner contour of the mask, a white or light-gray figure that is brighter than the background, or the description of seeing a target simultaneously with the mask or following the mask. Interrater agreement for these four categories as assessed by Cohen’s Kappa (modified according Brennan & Prediger, 1981) was moderate to high, $\kappa = 0.73$. To get an estimate of how often participants reported to see motion or afterimages, we averaged the frequency of cases in each category as classified by the two raters. Participants’ frequency of reports of each percept was taken as dependent variable in the free report section.

The analysis of data from the question section focuses on the questions about the experience of afterimages and motion (Question 4 and Question 6, see Table 1), and on the questions about the use of the experienced percept (Question 5 and Question 7, see Table 1). The results on the other questions are summarized in Table 2. Analyses on the experience of afterimages and motion were based on the frequency of trials on which participants only affirmed Question 4, only affirmed Question 6, or affirmed both questions. To increase readability we term affirmative responses on these two questions as “reports” of percepts of afterimages and motion, respectively.

Due to the lack of power that resulted from the small number of trials ($n = 8$ for each SOA) and the small number of participants in each group ($n = 6, 10, 10, 4$ for type-A observers, type-B observers, underachievers, and overachievers, respectively) we limited statistical analyses to three comparisons. First, we assessed the influence of SOA on the frequency of the reports separately for motion and afterimages in each group. Second, we compared the frequencies of reports between groups separately for each percept. Third, we compared the frequencies of reports of different percepts within each group. All comparisons were examined by resampling tests: In each case, we compared the difference of observed frequencies between two conditions with a distribution of frequency differences of the expected frequencies given the null-hypothesis. For within-subjects comparisons we first assessed for each participant the probability pooled across both conditions. Based on this individual probability we simulated reports for both conditions separately for each participant. These pseudo-observed report frequencies were then averaged across participants. The difference between these two averages reflected a possible data pattern which could have resulted if report frequencies did not differ between conditions. This procedure was repeated $10,000$ times resulting in a distribution of frequency differences under the null hypothesis. The fraction of simulations in which the expected difference was equal or exceeded the actual observed difference was taken as $p$-value. For between-subjects comparisons, we proceeded in the same way with the exception that the chance probability was estimated based on the frequency of reports of a specific percept pooled across all individuals.

To validate the relation between the reported subjective percepts and participants’ objective masking functions independently from our clustering, we
examined whether slope of the masking function in Session 2 of Experiment 1 correlates with the frequency of motion reports relative to reports of afterimages. To this end, we correlated the difference of the frequencies of motion reports and afterimage reports in Experiment 2 with the difference in performance with long SOA and short SOA in Session 2 of Experiment 1. By using the difference between report frequencies rather than proportions of each reported percept we controlled for individual biases to respond “yes” or “no.”

**Results**

**Free report section**

Figure 4a shows the mean percentages of reports for each group of observers. Contrary to our expectations, differences between short and long SOA were rather small in all conditions and groups (Table 3). Resampling tests did not reveal any significant differences between the short and the long SOA for reports of motion \( (p = 0.27, p = 0.58, p = 0.56, \) and \( p = 0.77, \) for type-A, type-B, underachievers, and overachievers, respectively) or reports of afterimages \( (p = 0.06, p = 0.63, p = 0.93, \) and \( p = 0.13. \) Therefore, we pooled the trials with short SOA and long SOA for all following analyses.

Between-groups comparisons of the free reports for each of the percepts yielded the following results: First, afterimages were reported on more trials by type-B than by type-A observers \( (p < 0.05) \) but not on more trials than by underachievers or overachievers \( (p = 0.36 \) and \( p = 0.10, \) respectively). Second, motion was reported more frequently by type-A than by type-B observers \( (p < 0.01) \) and underachievers \( (p < 0.05) \), but not more frequently than by overachievers \( (p = 0.30). \) Third, the frequency of reports of perceptions that comprise both, motion and afterimages on the same trial, did not differ between groups \( (all \) \( ps > 0.17) \).

Within-groups analyses were conducted to analyze the data in more detail. To this end we compared the frequency of trials on which each different type of percept was reported within each of the three groups with planned contrasts (see Figure 4a). Within the group of type-A observers, motion was reported on more trials than afterimages \( (p < 0.001) \) which were reported more often than a combination of motion and afterimages \( (p = 0.01) \). type-B observers reported afterimages more frequently than motion \( (p < 0.001) \) or a combination of motion and afterimages \( (p < 0.001) \). Underachievers reported afterimages on more trials than motion \( (p < 0.001) \), and motion more often than a combination of motion and afterimages \( (p < 0.01) \). Overachievers exhibited a data pattern similar to type-A observers in that the frequency of reports increased from both percepts to reports of afterimages to reports of motion. However, only the difference between both percepts and motion was significant \( (p < 0.05, both \) other \( ps > 0.10) \).

Figure 5a shows the relation between the reported subjective percepts and participants’ objective masking functions independently from our clustering. A correlational analysis revealed that this relation was significant \( (r = 0.52, p = 0.002). \) Thus, our findings suggest that it is possible to predict observers’ objective masking function from their subjective free reports on only 16 trials.

**Question section**

Again, we did not find a consistent effect of SOA on frequencies of reported percepts of motion and afterimages. Resampling tests did not reveal any significant differences between the short and the long SOA for reports of motion \( (p = 0.33, p = 0.90, p = 0.55, \) and \( p = 0.56, \) for type-A, type-B, underachievers, and overachievers, respectively) or reports of afterimages \( (p = 0.90, p = 0.91, p = 0.62, \) and \( p = 0.77). \) Therefore, we pooled trials with long and short SOAs for the following analyses.

Figure 4b shows average frequencies of trials on which participants reported to see only an afterimage, trials on which they reported to see only motion, trials on which they reported to see both, and trials on which they reported to see none of these percepts, separated for the four groups of observers. A comparison of Figures 4a and 3b shows that the frequency of trials on which participants reported to see neither an afterimage...
nor motion (14%, 20%, 33%, and 30% for type-A observers, type-B observers, underachievers, and over-achievers, respectively) was largely reduced in the question section, and these null-reports did not differ significantly between groups \( (p = 0.71) \). This finding suggests that participants are willing to report more percepts in response to specific questions. In the following, we analyzed the reports of the other three types of percepts.

Between-groups comparisons of the reported percepts revealed that afterimages were reported on more trials by type-B than type-A observers, underachievers, or overachievers observers \( (p < 0.01, p < 0.05, \) and \( p < 0.01, \) respectively) whereas the other groups did not differ (all \( ps > 0.15 \)). Motion, on the other hand, was reported more frequently by type-A observers and underachievers than type-B observers (both \( ps < 0.05 \)). Type-A observers and underachievers did not differ in their frequency of motion reports \( (p = 0.42) \). The frequency of reported motion percepts in overachievers did not differ from any other group (all \( ps > 0.12 \)). The frequency of trials on which participants reported both percepts was larger in type-A observers and overachievers than in type-B observers (both \( ps < 0.05 \) and \( p < 0.05, \) respectively). The frequency of reports of both percepts in type-A observers did not differ significantly from that of overachievers \( (p = 0.43) \), and that of type-B observers did not differ from that of underachievers \( (p = 0.35) \).

### Table 3. Mean proportions of reports of afterimages and motion as function of stimulus onset asynchrony (SOA) in Experiment 2.

<table>
<thead>
<tr>
<th></th>
<th>Type-A (n = 6)</th>
<th>Type-B (n = 10)</th>
<th>Underachiever (n = 10)</th>
<th>Overachiever (n = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Free report section</strong></td>
<td>24 ms</td>
<td>72 ms</td>
<td>24 ms</td>
<td>72 ms</td>
</tr>
<tr>
<td>Afterimage</td>
<td>12.5</td>
<td>4.2</td>
<td>32.5</td>
<td>33.8</td>
</tr>
<tr>
<td>Motion</td>
<td>33.3</td>
<td>27.1</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td><strong>Question section</strong></td>
<td>24 ms</td>
<td>72 ms</td>
<td>24 ms</td>
<td>72 ms</td>
</tr>
<tr>
<td>Afterimage</td>
<td>50.0</td>
<td>60.4</td>
<td>67.5</td>
<td>73.7</td>
</tr>
<tr>
<td>Motion</td>
<td>79.2</td>
<td>75.0</td>
<td>21.2</td>
<td>28.7</td>
</tr>
</tbody>
</table>
Within-groups comparisons revealed that type-A observers reported motion on most trials, most often together with afterimages but also as a single percept. On average, they reported to perceive both percepts simultaneously and motion only on more trials than afterimages ($p < 0.0001$ and $p < 0.001$, respectively). Type-B observers reported afterimages on most of the trials, mainly as a single percept but also together with motion. On average, afterimages were reported on more trials than motion or a combination of motion and afterimage (both $ps < 0.0001$). Underachievers reported motion on most of the trials, mainly as a single percept but also together with afterimages. On average, their reports were on more trials than motion or a combination of motion and afterimage only ($p < 0.05$) which were reported on more trials than afterimages and motion ($p < 0.01$). Overachievers showed a pattern similar to type-A observers. They reported both percepts simultaneously more often than motion ($p < 0.001$), which was reported more often than afterimages ($p < 0.05$). Figure 5b shows the relation between the reported subjective percepts and participants’ objective masking functions independently from our clustering. A correlational analyses revealed that this relation was significant ($r = 0.69, p < 0.0001$). This provides further evidence for a relationship between reported percepts and the time course of masking functions. Beyond this, within Experiment 2, the individual differences of the frequencies of motion reports and afterimage reports in the question section of Experiment 2 correlated significantly with the differences in proportion of correct responses in Experiment 2 at the long and short SOA (Q1 of the question section, $r = 0.41, p < 0.05$, Figure 5c). This means that participants with negative slopes of the masking function predominantly report afterimage percepts whereas participants with positive masking functions predominantly report motion percepts.

**Use of perceptual cues**

To learn whether participants actually use the percepts they claimed to perceive to discriminate target stimuli, we analyzed their response to the corresponding follow up questions (Figure 4c). Type-A observers most often claimed to use motion percepts in the discrimination task (75.8% motion vs. 29.7% afterimages). This difference of 46.1% was significant ($p < 0.0001$). Type-B observers most often claimed to use afterimages in the discrimination task. On average, type-B observers used afterimages on 80.0% of the trials, which is significantly more than motion, which was reported on 40.1% of the trials ($p < 0.0001$). Underachievers most often claimed to use motion in the discrimination task. The difference of 52.5% was significant ($p < 0.0001$). Overachievers reported on average to use motion on 94.8% of the trials, which is significantly more often than the use of afterimages, which was reported on 50.1% of the trials ($p < 0.001$).

**Discussion**

Experiment 2 yielded evidence for different predominant percepts in type-A and type-B observers. Type-A observers reported to see motion most often in their
free reports. When asked by the investigator, however, type-A observers also reported that they see afterimages in addition to motion on a great number of trials. Trials without motion percepts were few in this group. In addition, they claimed to use motion in most of the trials in the target discrimination task, much more often than afterimages. However, participants of this group seem to have access to percepts of afterimages when the investigator pointed to this possibility.

Type-B observers freely reported to see nothing but afterimages on most of the trials and affirmed only the corresponding question on most of the trials when the investigator explicitly asked them. Beyond this, they claimed to use afterimages to discriminate the target stimuli on most of the trials when they experienced afterimages. These findings suggest type-B observers do not have easy access to motion percepts even when they are pointed to this possibility by the investigator’s questions. Nonetheless, some of them claimed that they used motion on part of the trials to discriminate targets.

These findings suggest that different masking functions in metacontrast masking with our stimuli design and task conditions indeed reflect different phenomenological experiences in type-A and type-B observers. Both groups seem to have access to afterimages. However, type-A observers seem to be superior to type-B observers in respect of motion cues, either because they have better access to motion percepts than type-B observers, or because motion percepts emerge more easily in type-A than in type-B observers. On the other hand, however, the possibility to see motion and afterimages alone does not automatically have the consequence that participants use these percepts in the discrimination task. Instead, type-B observers report to see motion on only a few trials, but some of them claim to use this information frequently to do the task, whereas type-A observers report to see afterimages on most of the trials but they use motion more often to do the task. This corresponds to a previous finding, which suggests that both type-A and type-B observers have difficulties to change their criterion in the discrimination task: When participants did the discrimination task with a fixed SOA that was selected to be the most difficult for each individual participant, performance remained poor across a series of 288 trials despite error feedback on each trial (Albrecht, Klápötte et al., 2010).

Underachievers’ objective performance was near chance at all SOAs in Experiment 1. However, their subjective reports were similar to those of participants with better objective performance. Underachievers reported to see afterimages slightly more often than motion in free reports. This finding suggests that the experience of percepts does not automatically result in the successful use of these percepts in the discrimination task. However, when the investigator asked them explicitly, underachievers affirmed to see motion on more trials than afterimages. This shift in responses may suggest that underachievers have little confidence in their percepts. Moreover, they claimed on most of the trials that they used motion to discriminate target stimuli. These findings suggest that underachievers do not lack the phenomenological experiences that have been reported by the other participants. Nonetheless, the overall poor performance of underachievers suggests that the claim to use a certain percept to do the task has to be distinguished from successful performance in the discrimination task.

The small group of overachievers who showed superior performance at all levels of SOAs in Experiment 1 reported subjective experiences that are similar to those of type-A observers. This finding adds to the similarities between both groups in response biases and discrimination performance in Experiment 1 and suggests that participants of this group perceive and recruit the same perceptual cues as type-A observers. To account for their improved level of objective performance, we speculate that this group might use perceptual cues more successfully than type-A observers. Further research is needed to examine the relation between these two groups of observers.

Across groups, free reports and the answers to our questions did not differ much on trials with short and long SOA. Thus, contrary to our expectations, the experience of motion percepts does not seem to require long SOAs between target and mask, and the experience of afterimages does not require short SOAs. Instead, the emergence of experienced percepts seems to be independent of SOA. This finding questions the view that the experience of specific percepts is sufficient for the successful use of these percepts because the phenomenological reports contrast with the masking functions of type-A and type-B observers. If percepts are indeed used in the discrimination task, the different masking functions show that the successful use of percepts does depend on SOA. This could result if motion percepts can be used reliably to discriminate target stimuli only with long SOAs, whereas afterimages are reliable cues for this task only with short SOAs. Therefore, type-A observers perform better with long SOAs than with short SOAs and type-B observers perform better with short SOAs than with long SOAs. Note that subtle SOA effects on motion percepts may be unresolved here because we omitted fine grained distinctions between different kinds of motion percepts like rotation and enlargement (see also Footnote 1). However, this does not apply to the lack of SOA-effects on percepts of afterimages.

Experiment 2 was intended as a first approach to examining participants’ subjective experience in the metacontrast masking paradigm. However, participants’ objective performance in Experiment 2 (see Table 2) is much below that of the second session in
Experiment 1 (Figure 2). On the one hand, this finding corroborates previous reports indicating that objective performance in metacontrast masking is modulated by the task that participants are instructed to perform (e.g., Kahneman, 1968; Breitmeyer, Kafalogul et al., 2006). Whereas participants were only asked to answer correctly which target stimulus was presented in Experiment 1, their task was much more complex in Experiment 2. Beyond the target discrimination task, participants could also anticipate a specific series of questions on their subjective experience and they were instructed that there was no objectively “correct” answer in these items of Experiment 2. In consequence, the modulatory effect of task instructions is potentially limiting the interpretation of the present subjective reports because it is not clear how the subjective reports in Experiment 2 relate to the subjective experience in Experiment 1. Our correlational analyses, however, revealed some evidence for a relation of subjective experiences and the performance in the objective discrimination task: Participants who performed better at long SOA rather than short SOA in Experiment 1 reported more motion percepts than afterimage percepts in Experiment 2. This finding suggests that individual differences in masking functions are accompanied by individual differences in subjective perceptual experience. Future studies have to address this issue to shed more light on the interesting question how objective performance is related to subjective experience on a trial-to-trial basis.

To sum up, the results of the phenomenological experiment suggest five distinctions. (A) Participants differ regarding which specific aspects of the target-mask sequence they experience predominantly: type-B observers tend to experience a form of light afterimage of the target, type-A observers and the group of overachievers tend to experience apparent motion or both, afterimage and motion. The group of underachievers showed ambiguous experiences: When they were to freely describe their percept they reported experiences similar to type-B observers, but when they were asked explicitly about their percepts they reported to perceive afterimages or motion, but not both. (B) Participants have different abilities to access those aspects of percepts that differ from their predominant type of experience. This is indicated by type-A observers’ reports to experience perceptions of motion and percepts of afterimages more often than type-B observers. (C) Participants’ ability to experience specific percepts does not determine whether they use these percepts successfully to do the discrimination task. Type-A observers claim to experience motion and afterimages on most of the trials but to use motion more often as a cue in the discrimination task. (D) Neither participants’ reports of specific experiences nor their claims to use the corresponding perceptual cue in the discrimination task determine whether they are successful in doing the task. This is evident from the differential effect of SOA: Whereas the emergence of experiences does not depend on SOA, their successful use seems to depend on SOA. (E) Finally, the low performance of underachievers suggests that the ability to experience a specific percept is not sufficient to perform successfully at any SOA in the discrimination task. Participants’ motivation or their ability to use corresponding perceptual cues successfully is also required.

### Experiment 3

On the one hand, the contrast in free reports and the answers to explicit questions in Experiment 2 suggests that at least some participants recollect their nondominant percepts more often after the corresponding question of the investigator. This finding suggests that participants have access to several aspects of percepts and might be able to use these as perceptual cues when given an appropriate instruction. On the other hand, participants of Experiment 2 did not claim to use all aspects of percepts that they experience to the same degree. Instead, they tended to base their discrimination judgment on their predominant type of percept. As mentioned above, the latter finding accords well with our previous study (Albrecht, Klapotke et al., 2010), which has shown that participants’ performance did not improve during a series of 288 trials in which each participant did the discrimination task with the SOA that was most difficult for her/him. Findings of Experiment 2 suggest distinctions between access to different aspects of percepts, the claimed use of them in the discrimination task, and the ability to use percepts successfully. Therefore, we examined in Experiment 3 whether participants can be instructed to use both types of percepts successfully in the discrimination task.

Based on our own observations and the reports of participants in Experiment 2, we assumed that motion percepts enhance performance with long SOAs (see also Maksimov et al., 2011) and afterimages support performance with short SOAs. If participants have the ability to voluntarily weight the impact of either percept, we expected that they should show type-A masking functions when a cue indicates to use motion and type-B masking functions when the cue indicates to use afterimages. We tested this hypothesis in Experiment 3. On each trial, we presented a cue which indicated either to use afterimages or motion percepts as the bases for the discrimination of the target shapes. Motion cues were followed by a stimulus-sequence with long SOA on 75% of the trials, whereas afterimage cues were followed by a stimulus-sequence with short SOA on 75% of the trials.
Method

Participants

Twenty-nine participants of Experiment 1 were tested in two one-hour sessions. One underachiever refused to participate any longer.

Task, stimuli, and procedure

The experiment was identical to Session 2 of Experiment 1 with the only exception that a cue was presented for 1500 milliseconds at the beginning of each trial in the center of the screen. The word “bewegung” (German for motion) was used as a cue to instruct participants to attend to motion and the word “nachbild” (German for afterimage) was used as a cue to instruct participants to attend to afterimages. On 75% of the trials, a motion cue was followed by a trial with 72 milliseconds SOA and an afterimage cue by a trial with 24 milliseconds SOA. On 25% of the trials, a motion cue was followed by trial with 24 milliseconds SOA and an afterimage cue by a trial with 72 milliseconds SOA. We employed this correlation between cue and SOA because we anticipated that participants would be reinforced to use instructed cues given that motion cues are most helpful with long and afterimage-cues with short SOA.

Before the start of the experiment, the instructor explained participants the concept of “afterimages” and “motion.” “Afterimages” were described as white or light-gray images with the shape of the target, which appears at the same position as the target and might persist even when the mask is presented. “Motion” was described as (a) either a smooth motion out of the screen or an enlargement or (b) as a flip or a rotation. In the former case, participants were encouraged to infer that target and mask were of the same shape, in the latter case they were encouraged to infer that target and mask were of different shapes.

Statistical analysis

In line with the analyses of Experiment 1, we examined participants’ performance in terms of measures of sensitivity (d′) and response bias (C). In contrast to Experiment 1, we omitted analyses based on the clustering of groups to avoid statistical problems of small group comparisons. Instead, we conducted correlational analyses that are independent from clustering. To this end, we assessed the slope of the masking function in Session 2 of Experiment 1 by calculating the difference of d′ with 72 milliseconds SOA minus d′ with 24 milliseconds SOA. To examine the relationship between the relative utility of the cues and the masking function, we correlated participants’ slope of the masking function with a measure of the predominance of the motion cue effect relative to the effect of the afterimage cue. The predominance of the motion cue effect relative to the effect of the afterimage cue was assessed by the difference in d′ with motion cues minus d′ with afterimage cues. A positive value indicates superior performance with motion cues, and a negative value results from superior performance with afterimage cues.

Results

Visual inspection of sensitivity and response bias in Figure 6 suggests, that the average performance of the entire sample of 29 participants became similar to the performance of type-A observers in Experiment 1 when the motion cue was given. This performance is characterized by a masking function with positive slope (compare Figures 6a and 2f) and a substantial response bias with short SOAs where the response is mainly determined by the shape of the mask (Figure 6c and 3a). In stark contrast, when the afterimage cue was given, average performance of the entire sample became similar to the performance of type-B observers in Experiment 1, which is characterized by a masking function with negative slope (compare Figures 6a and 2f) and the virtual absence of response bias (Figure 6b and 3b). This was corroborated by statistical analyses.

Cueing effects on sensitivity

Figure 6a shows the discrimination performance in terms of d′ as function of SOA and cue-type. A two-way ANOVA revealed a significant interaction of SOA × Cue (F[1, 28] = 33.9, p < 0.0001), and a marginal significant main effect of SOA (F[1, 28] = 4.08, p = 0.05), but no main effect of cue (F[1, 28] = 0.3, p > 0.58). Post-hoc t-tests revealed that d′ was significantly modulated by the type of cue with both short and long SOA (t[28] = 4.34, p = 0.0002, and t[28] = −3.35, p = 0.002, respectively). Thus, motion- and afterimage-cues modulated participants’ performance in the metacontrast masking task irrespective of their masking function. Compared to the motion-cue, the afterimage-cue reduced performance with long SOA but improved performance with short SOA.

Overall, participants’ masking functions in the present experiment were highly similar to the masking functions that they produced in Session 2 of Experiment 1, irrespective of the given cue in Experiment 3. The slope of participants’ masking functions in both experiments correlated significantly (r = 0.69, p < 0.0001 and r = 0.82, p < 0.0001 for masking functions based on trials with afterimage-cues and motion-cues, respectively; Figure 7a). Thus, the cues did not fully
determine individual masking functions. To examine whether the difference of the motion cueing effect relative to the afterimage cueing effect is related to participants' masking functions in Experiment 1 we correlated the slope of the masking functions in Session 2 of Experiment 1 with the difference between cueing effects (Figure 7b). This correlation was significant ($r = 0.63, p < 0.001$). This finding suggests that participants with a positive slope of the masking function in Experiment 1 (type-A observers) performed superior with motion rather than afterimage cues, whereas participants with negative slopes in Experiment 1 (type-B observers) performed superior with afterimage cues rather than motion cues. Participants with flat masking functions in Experiment 1 (overachievers and underachievers) showed about the same performance with both types of cues.

Cueing effects on response bias

Figures 6b and 6c show measures of response bias in terms of criterion C as a function of SOA and shape of mask (diamond vs. square), for afterimage cue and motion cue, respectively. A three-way ANOVA with SOA, cue, and shape of mask as independent variables revealed significant interactions of SOA $\times$ Mask ($F[1, 28] = 20.9, p < 0.001$), Cue $\times$ Mask ($F[1, 28] = 12.29, p < 0.01$), and SOA $\times$ Cue $\times$ Mask ($F[1, 28] = 14.01, p < 0.001$). Separate analyses for each cue revealed a significant interaction of SOA $\times$ Mask on trials with the motion cue ($F[1, 28] = 24.4, p < 0.0001$) and a significant but reversed interaction with the afterimage cue ($F[1, 28] = 5.6, p < 0.05$). This finding suggests that the motion cue induces a response bias only with short SOAs but not with long SOA. An afterimage cue induces no response bias with short SOA and seemingly a small response bias at the long SOA. Thus, when participants were instructed to use perceptual motion cues to perform the task, participants’ response was determined to a large extent by the shape of the mask, at least with short SOA (see below).

Discussion

On the one hand, participants' individual masking functions of Experiment 1 were reproduced in Experiment 3 irrespective of cueing instructions. This finding is new evidence for the stability of individuals' masking functions in different experimental contexts (see Albrecht, Klapötke et al., 2010). On the other hand, however, participants’ performance was also modulated by cues in Experiment 3, indicating that they followed instructions and used the cues. With short SOA, performance was superior with afterimage cues but with long SOA, performance was superior with motion cues. This finding is consistent with our hypothesis that afterimages are reliable perceptual cues with short SOA and apparent motion is a reliable perceptual cue with long SOAs. Moreover, the slopes of participants' masking functions were correlated with the relative usefulness of motion as compared to afterimage cues. The scatterplot of this relationship in Figure 7 suggests that participants with positive slopes (type-A observers) benefitted more from the motion cue rather than the afterimage cue, whereas participants with negative slopes (type-B observers) profited more from the afterimage cue than the motion cue.
Findings of response bias analyses provide additional evidence for the view that participants used the instructional cue. This is evident from the finding that participants exhibited a strong response bias towards the outer shape of the masks with short but not long SOA when a motion cue was given. Evidence for cue use comes also from the finding that afterimage cues did not produce a pronounced systematic response bias difference between SOAs. Whereas the former pattern of response biases resembles that of type-A observers in Experiment 1 (Figure 3a), the latter pattern resembles that of type-B observers in Experiment 1 (Figure 3b).

Together, findings suggest that the successful usage of motion cues leads to a shift in performance towards the pattern that is characteristically for type-A observers, whereas the usage of afterimage cues shifts performance towards a pattern, which corresponds to that of type-B observers. As seen in the response bias C, the usage of afterimage cues seems to lead to a response strategy that is rather independent from the shape of the mask (especially with short SOAs), whereas motion cues seem to lead to a response strategy that takes into account perceived motion and the shape of the mask. Findings fit nicely into our proposal mentioned above, that type-A observers report a target corresponding to the shape of the mask if rotational motion is absent and a target opposite to the shape of the mask if motion is seen. We speculate that this strategy is uncovered on trials with short SOAs where participants do not perceive motion and erroneously report the shape of the mask even on congruent trials, which produces the observed response bias with short SOA (see also Albrecht & Mattler, in press).

Experiment 4

Experiment 4 intended to replicate findings of Experiment 3 with a fresh sample of naïve participants who had not such an extensive amount of practice as the participants who performed Experiments 1 to 3. Moreover, in Experiment 4 the instructional cue was uncorrelated with SOA. If uncorrelated cues produce the same cueing effects like Experiment 3, were motion cues predicted a long SOA and afterimage cues predicted a short SOA, it would provide evidence for the view that the usage of specific perceptual cues modulates performance rather than the expectancy of short or long SOAs. We tested participants in two one-hour sessions each. In the first session, participants practiced the task without cues to develop a stable masking function. In the second session, they did the task with the two cues which were followed by a short and long SOA half of the trials each.

Methods

Participants

Thirty-one new participants (25 female, 6 male) were tested in two one-hour sessions. Their age varied between 19 to 30 years (M = 21.9 years, SD = 2.47 years). All had normal or corrected to normal vision and received partial course credit or monetary reward. All gave their informed consent. No participant had previously taken part in any visual masking experiment.
Task, stimuli, and procedure

Session 1 of Experiment 4 was identical to Session 1 of Experiment 1. Participants performed a discrimination task on metacontrast masked target stimuli. Targets and masks were presented with six different SOAs (24, 36, 48, 60, 72, and 84 milliseconds). Session 2 was identical to Experiment 3 with the following exceptions: First, each cue was followed by each SOA on 50% of all trials, so that the cue did not predict the following SOA. Second, after each experimental block of 48 trials, participants rated their ability to focus on the cued strategy on a scale from 1 (“not at all”) to 5 (“excellent”). Statistical analyses were the same as in Experiment 3.

Results
Session 1

Figure 8a shows the mean discrimination performance in the first session as a function of SOA. On average, the discrimination performance was significantly modulated by SOA ($F[5, 150] = 4.8, p < 0.001$) and performance peaked with 24 milliseconds SOA ($d' = 1.0$). With SOAs > 24 milliseconds performance was reduced ($0.57 < d' < 0.72$). Inspection of individual masking functions revealed substantial interindividual variability of masking functions (see Supplementary Figures S2 and S3).

Figure 8b shows the average response bias for each SOA and mask in the first session. On average, response criterion decreased slightly with increasing SOA ($F[5, 150] = 3.66, p < 0.01$). This effect of SOA was modulated by the shape of the mask as reflected by the significant interaction of SOA $\times$ Mask ($F[5, 150] = 9.87, p < 0.0001$). This finding indicates that the response bias was determined by the two masks especially with short SOAs. Again, inspection of individual data reveals some interindividual variability (see Supplementary information).

Session 2

On average, participants reported that they felt moderately able to focus on the percept indicated by the cue (mean score on a five-point scale $M = 3.3$, range 1.8–4.2). These reports suggest that participants did attend to the instructed perceptual cues in Experiment 4 although cues were not correlated with any potentially helpful event. Visual inspection of performance measures $d'$ and response bias in Figure 9 suggests that the pattern of results resembles the pattern of Experiment 3 (Figure 6) although participants of the sample in Experiment 4 produced predominantly masking functions with negative slopes.

Cueing effects on sensitivity

Figure 9a shows the mean discrimination performance in the second session as function of SOA and cue. A two-way ANOVA revealed that performance was better with short SOA than with long SOA (main effect SOA: $F[1, 30] = 4.84, p < 0.05$). Performance was marginally better with the motion cue than with the afterimage cue ($F[1, 30] = 3.68, p = 0.06$). Most important, however, cues affected performance differentially at each SOA as reflected by the significant interaction SOA $\times$ Cue ($F[1, 30] = 7.76, p < 0.01$). Post-hoc $t$-tests revealed that the cueing effect was significant

Figure 8. Discrimination performance in terms of sensitivity (a) and response bias (b) in Experiment 4, Session 1.
with long SOA \((t[30] = 3.55, p < 0.01)\) but not with short SOA \((t[30] = 0.24, p = 0.82)\).

Individual masking functions remained stable across both sessions as revealed by correlations of the slopes of individuals’ masking functions from Session 1 and the slopes of their functions from Session 2 on trials with afterimage cues \((r = 0.77, p < 0.0001)\) and trials with motion cues \((r = 0.75, p < 0.0001, \text{Figure 10a})\). Moreover, the slope of the masking function in Session 1 (without cues) correlated significantly with the difference of the cueing effect with motion cues as compared to the cueing effect with afterimage cues in Session 2 \((r = 0.45, p < 0.01, \text{Figure 10b})\).

Cueing effects on response bias

Figures 5b and 5c show measures of response bias in terms of criterion C as a function of SOA and shape of mask (diamond vs. square), for afterimage cue and motion cue, respectively. A three-way ANOVA with SOA, cue, and mask as independent variables revealed significant interactions of SOA \(\times\) Cue \((F[1, 30] = 34.55, p < 0.0001)\), Cue \(\times\) Mask \((F[1, 30] = 9.59, p < 0.01)\), and SOA \(\times\) Cue \(\times\) Mask \((F[1, 28] = 9.36, p < 0.01)\). No other effect was significant \((all \ ps > 0.19)\). Separate analyses on trials with afterimage and motion cues, respectively, revealed that the interaction of SOA \(\times\) Mask was significant for the motion cue \((F[1, 30] = 7.74, p < 0.01)\) but not for the afterimage cue \((F[1, 30] = 4.1, p > 0.05)\).

Discussion

Although the cues were not predictive of SOA, Experiment 4 replicated findings of Experiment 3 in a fresh sample of naïve participants who did not have the extended practice of participants in Experiment 3. Again, the slope of participants’ masking functions in the first session correlated positively with the slope of their masking functions when they attended to cued aspects of the stimulus sequence. This finding supports the notion that individual differences in masking functions remain relatively stable in varying experimental contexts. Nonetheless, participants’ masking functions were modulated by cueing. Replicating findings of Experiment 3, the scatterplot of this relationship in Figure 10 suggests that the performance benefit from motion cues was larger than that of afterimage-cues in participants with positive slope masking functions (e.g., type-A observers) whereas the benefit from afterimage cues was superior in participants with negative slope masking functions (e.g., type-B observers). Analyses of the response bias replicated findings of earlier experiments of this and a previous study (Albrecht & Mattler, in press). When instructed to use afterimages as cues, participants apparently adopted a response strategy that was largely independent of the shape of the mask. When a motion cue was given, participants’ response was largely determined by the shape of the mask when SOA was short. This performance pattern is explained by our proposal mentioned above.

General discussion

When participants performed a masked stimulus discrimination task with target and mask stimuli that were either congruent or incongruent, we found
individual masking functions that could be categorized into one of four groups. In addition to the previously distinguished type-A and type-B observers (Albrecht, Klapötke et al., 2010), we found a group of underachievers who performed at a low level across the entire range of the examined SOA and a group of overachievers who performed at high levels irrespective of SOA. Phenomenological testing in Experiment 2 by either free reports or explicit questions revealed specific contents of conscious perception in these four groups. Type-A observers and overachievers seem to experience motion and afterimages but they report to predominantly use motion percepts, whereas type-B observers predominantly experience afterimages and, in accordance with this, report to predominantly use afterimages to solve the task. Underachievers reported to experience percepts of motion and afterimages irrespective of SOA, but they could not use any of these percepts successfully at any level of SOA. Thus, the experience of specific percepts has to be distinguished on the one hand from the ability to use these percepts in the discrimination task, and on the other hand from success in the discrimination task. Type-B observers have difficulties to perceive motion in a metaccontrast sequence further suggests that participants also differ in their ability to experience specific percepts. Nonetheless, Experiment 3 and Experiment 4 revealed that all observers adjust their performance pattern when we instructed them to attend either to motion or to afterimages. These findings suggest that participants can change their focus of attention in this task. On the other hand, however, the slope of participants’ masking function was highly correlated in conditions with and without cueing. The later finding contributes evidence to the view that individual masking functions remain relatively stable (see also Albrecht, Klapötke et al., 2010). Although our experiments yielded stable individual differences that are interesting on their own, further studies are needed to determine the generality of these findings for other instances of metaccontrast masking and the role of the congruency between the shape of the target and the mask.

The relation between subjective experience and objective performance

In two experiments, predominant reports of motion percepts were related to superior performance in the discrimination task with long over short SOA, whereas predominant reports of afterimage percepts were related to superior performance with short over long SOA. The frequency of the reported percepts, however, did not vary with SOA in the present study, neither in free reports nor in the answers to our questions. This stands in contradiction to earlier studies, which have documented subjective reports of afterimages and apparent motion in visual masking (e.g., Werner, 1935). These studies reported a clear relation between subjective percepts and specific SOAs.

The independence of subjective percepts from SOA in the present study may have resulted from differences between this and previous studies. For instance, we measured subjective percepts with a rather small number of trials in each SOA condition and each
participant, and the statistical power might have been insufficient to find the effect of SOA. In addition, different kinds of motion may be linked to short and long SOAs, so that assessing the kind of motion percept in more detail would have been necessary to unveil SOA effects on subjective experiences. Alternatively, the absence of SOA effects on subjective percepts might be due to participants’ initial orientation of attention to specific aspects of the stimulus sequence and perceptual learning effects at the level of subjective experience. Studies of Carrasco and colleagues (Carrasco, Ling, & Read, 2004; van Boxtel, Tsuchiya, & Koch, 2010) suggest that the allocation of attention can alter the appearance of visual stimuli. In addition, Schwiedrzik, Singer, and Melloni (2011) showed that the subjective ability to discriminate metacontrast masked stimuli increases over the course of an experiment and that this perceptual learning generalizes across different stimulus position. In contrast, the objective ability to discriminate metacontrast masked stimuli did not generalize across positions. Thus, although participants think they are able to discriminate masked stimuli they are in fact not. In a similar way, our participants might have learned to perceive either expected motion or afterimages in Experiment 1, and these top-down expectancies might have influenced their subjective experience of motion and afterimages across SOAs. Irrespective of the cause of the absence of SOA effects in subjective reports, it is most important that subjective experience and objective performance are dissociated by the effect of SOA. We hypothesize, however, that subjective and objective performance can be linked if the information provided by percepts of motion and afterimages is reliable for successful performance in the target discrimination task only at specific SOAs. Motion percepts may provide reliable information for target discrimination only with long SOAs whereas afterimages may provide reliable information for successful target discrimination only with short SOAs.

Despite the dissociation of subjective experience and objective performance by SOA, there was a clear relation between individual’s percepts and their objective masking functions. Findings of Experiment 2 showed that the slope of participants’ masking functions can be predicted from participants’ reports in the phenomenological session. This finding exemplifies the potential usefulness of combining phenomenological and psychophysical measures and provides a clue to the possibility to develop methods for predicting objective individual performance from subjective reports. Previous research has suggested that type-A and type-B masking functions depend on the criterion content of participants (e.g., Kahneman, 1968, Breitmeyer, Kafaliğonül et al., 2006). Based on our findings, we assume that criterion content is also related to subjectively experienced percepts.

### Stability of criterion content

The slope of participants’ masking functions remained relatively stable from Experiment 1 to Experiment 3, and also within sessions of Experiment 4 despite different experimental contexts. Type-B observers were especially noticeable because they exhibited peculiar difficulties to perceive motion in the stimulus sequence. Individual predispositions towards one percept of the stimulus sequence could result from individually different perceptual capabilities (Withagen & van Wermeskerken, 2009). Participants might have acquired these different capabilities through perceptual learning in Experiment 1. This view is consistent with the Reverse Hierarchy Theory (Ahissar & Hochstein, 1993, 1997) which assumes two phases in perceptual learning: an initial attentional phase in which the appropriate processing level is determined and a following phase of plasticity in which the neural structure at the selected level changes. From this perspective, individually different percepts and masking functions may result because individual predispositions determine the initial selection of a specific neuronal level of processing where the discrimination task is performed. Alternatively, however, individual differences could also result from coincidental selections of one out of two neuronal levels and some kind of winner-takes-all process that strengthens the selection during perceptual learning.

### Underachievers and overachievers

In addition to participants with either increasing or decreasing masking functions (type-A observers and type-B observers respectively), several participants in Experiment 1 produced characteristically flat “masking functions”: underachievers with poor performance at all levels of SOA, and overachievers with very high performance at all levels of SOA. In Experiment 2, underachievers appeared to be rather uncertain about what percepts they experience because they changed their reports fundamentally from the free report section to the question section when the investigator directed their attention to afterimages and motion percepts. On first glance, this data pattern may be caused by a general lack of motivation which may have hindered participants to do the discrimination task. It is difficult to assess participants’ motivation to do a task. However, underachievers did not fail to do the task in Experiment 2 because the frequency of their subjective reports including either motion or afterimages did not differ from those of the other observers. Alternatively, a data pattern with poor performance across all levels of SOA may result because observers do not experience any reliable percept in the discrimin-
ination task. However, this view conflicts with the reports of underachievers in Experiment 2, which were at least partially similar to those of type-A observers.

On the other hand, several studies have shown that metacontrast masking is affected by practice. Whereas most of these studies found that practice reduced masking (Ventura, 1980; Hogben & Di Lollo, 1984; Schwiedrzik, Singer, & Melloni, 2009), our previous study showed that participants’ initial masking functions were pronounced with practice on the task (Albrecht, Klapötke et al. 2010). In consequence, if underachievers would get sufficient practice they might exhibit masking functions with above chance level performance, which correspond to those of the other groups. Beyond this, it is also possible that type-A and type-B observers might reach the performance levels of overachievers after extensive practice. This might result if sufficient practice improves participants’ ability to use different perceptual cues to do the task. In this perspective, the slope of the masking function of an individual simply reflects the participant’s ability to use specific perceptual cues. Further research is needed to clarify this issue.

Conclusion

The present study confirms and extends our previous findings of individual differences in a basic visual perception task (Albrecht, Klapötke et al., 2010). Previous evidence for the stability of individually different masking functions (Albrecht, Klapötke et al., 2010) has been further confirmed by two cueing experiments, which showed that participants’ initial masking functions correlate with masking functions in different experimental contexts. In addition, however, participants’ performance was also modulated by the instruction to use specific perceptual cues to perform the task. Our phenomenological session revealed that objectively measured individually different masking functions correspond to individually different subjective reports of consciously experienced percepts. In sum, the data that we have collected so far suggests that individuals with different masking functions do actually differ also in terms of phenomenology, the perceptual cues that are predominantly used, and the response strategy. These findings encourage the view that participants with similar types of masking functions in the metacontrast masking paradigm also share other communalities, whereas participants with different types of masking functions differ in additional aspects. We think these findings encourage the consideration of individual differences in metacontrast masking.

Acknowledgments

Commercial relationships: none.
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Footnote

In this experiment we did not try to differentiate between different types of motion percepts. Some participants reported rotation and some enlargement. However, the few reports did not allow for analyzing differences between these kinds of motion percepts due to small and roughly equal numbers of reports for each kind of motion. Nevertheless, it seems worthwhile for future research to assess different kinds of motion percepts more carefully and examine their relation to objective discrimination performance.

References


Albrecht, T., Klapötke, S., & Mattler, U. (2010). Individual differences in the metacontrast masking paradigm also share other communalities, whereas participants with different types of masking functions differ in additional aspects. We think these findings encourage the consideration of individual differences in metacontrast masking.


