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Individual differences in metacontrast masking are enhanced by perceptual learning

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A B S T R A C T

In vision research metacontrast masking is a widely used technique to reduce the visibility of a stimulus. Typically, studies attempt to reveal general principles that apply to a large majority of participants and tend to omit possible individual differences. The neural plasticity of the visual system, however, entails the potential capability for individual differences in the way observers perform perceptual tasks. We report a case of perceptual learning in a metacontrast masking task that leads to the enhancement of two types of adult human observers despite identical learning conditions. In a priming task both types of observers exhibited the same priming effects, which were insensitive to learning. Findings suggest that visual processing of target stimuli in the metacontrast masking task is based on neural levels with sufficient plasticity to enable the development of two types of observers, which do not contribute to processing of target stimuli in the priming task.

1. Introduction

One approach to understanding visual perception is to examine participants' ability to discriminate stimuli in conditions with limited sensory input. Psychophysical studies have used masking procedure to limit the sensory input and to examine stimulation parameters that determine participants' performance in perceptual tasks (e.g., Bachmann, 1984, 1994; Breitmeyer & Ögmen, 2006; Turvey, 1973). However, also using masking, priming studies have demonstrated processing of subliminal stimuli that participants cannot discriminate (e.g., Eimer & Schlaghecken, 1998; Fehrer & Raab, 1962; Klotz & Neumann, 1999; Marcel, 1983; Mattler, 2003; Neumann & Klotz, 1994; Schmidt, 2000, 2002; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). Interestingly, this literature does not address individual differences because it focuses on general principles of perception that apply to a large majority of participants. However, due to the neural plasticity in the visual system, differences in individual perceptual experience are potentially capable of modifying observers' performance in perceptual tasks that could result in stable individual differences in performing specific tasks.

Perceptual learning ranges from long lasting effects of a single exposure to a stimulus to the improved ability to perform specific perceptual tasks after substantial practice (Fahle & Poggio, 2002). In addition to differences in the amount of practice, stable individual differences might also result when specific predispositions render observers more efficient in stimulus processing at certain levels in 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). For instance, the Reverse Hierarchy Theory (RHT, Ahissar & Hochstein, 1993, 1997) 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

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which the neural structure at the selected level changes. This theory could explain individual differences in perceptual tasks by assuming that individuals can select different processing levels to perform a task. A similar prediction has been made by ecologically motivated accounts of perceptual learning, which assume individual differences occur due to participants' use of different informational variables (e.g., Jacobs, Runeson, & Michaels, 2001; Runeson & Andersson, 2007; Withagen & van Wermeskerken, 2009). Here we report a case in which qualitative individual differences developed and stabilized spontaneously despite identical learning conditions.

We used a metacontrast masking paradigm, in which the target stimulus is followed by a mask, whose contours are displayed contiguous to the contours of the target (Fig. 1a and b). Under these conditions target visibility is a function of the stimulus onset asynchrony (SOA) between the target and the mask. Two types of masking functions have been traditionally distinguished. With Type A functions target visibility is minimal at short SOAs and increases with increasing SOA. With Type B functions target visibility follows an U-shaped function with minimal target visibility at intermediate SOAs (Kolers, 1962). According to previous research, the type of the masking function is determined by the relation between the duration and/or intensity of mask and target stimuli (Breitmeyer & Ögmen, 2000), and by the spatial layout of the stimuli (Duangudom, Francis, & Herzog, 2007; Francis & Cho, 2008; Francis & Herzog, 2004). Attentional effects have been found to affect the level rather than the type of the masking function (Ramachandran & Cobb, 1995; Shelley-Tremblay & Mack, 1999). However, as an exception to these findings, Weisstein (1966) reported that the peak of Type B masking functions shifted towards smaller SOAs when attention had to be divided across several spatial positions rather than being focused on one position alone.

Type B masking functions have typically been found in brightness rating tasks, whereas Type A masking functions result from simple detection and speeded response time tasks (for a review, see Breitmeyer & Ögmen, 2006). Task dependent differences in metacontrast masking have been explained by the assumption that participants apply different criterion contents when they perform different tasks. Criterion content refers to the stimulus attribute, psychological dimension or perceptual

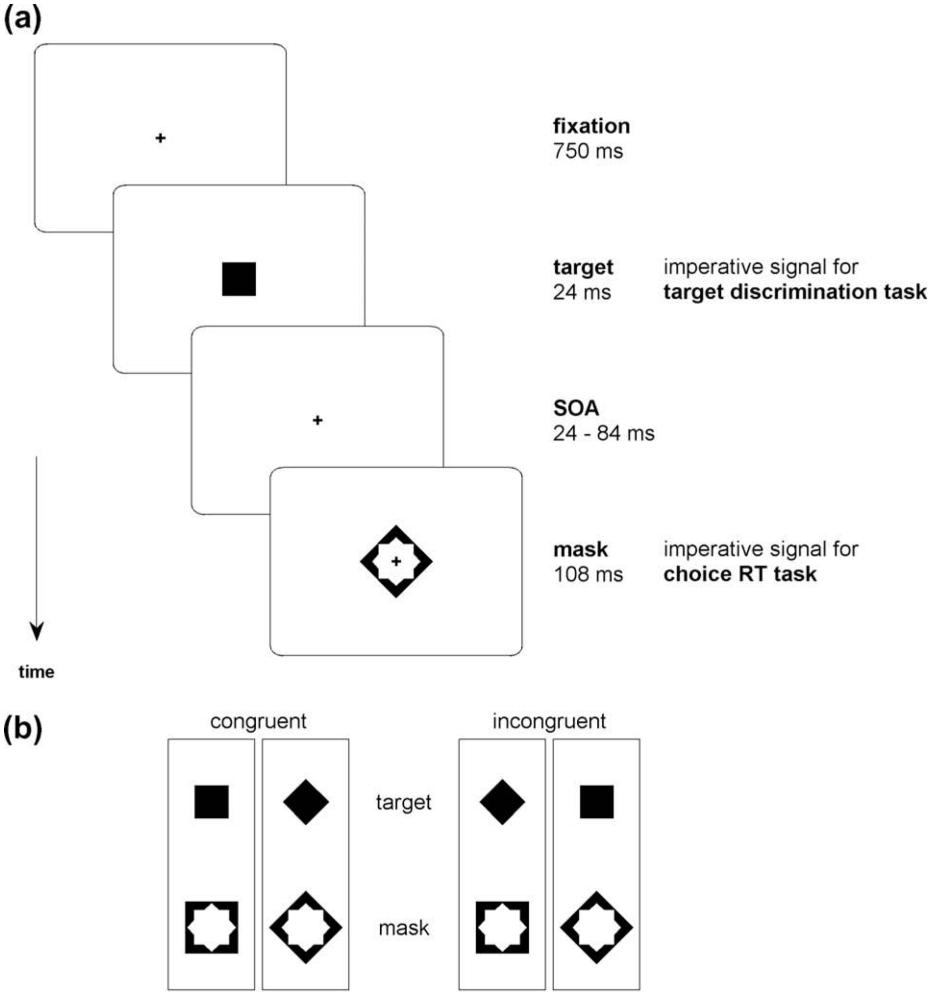

Fig. 1. Trial sequence and stimuli. (a) Sequence of Events. (b) Target and masking stimuli.

cue a judgment is based on (Ventura, 1980). A change of criterion content has also been assumed to account for the finding that Type B metacontrast masking can be reduced or even absent after several sessions of practice (Hogben & DiLollo, 1984; Ventura, 1980). Ventura (1980), for instance, has used a stimulus sequence that elicited a biphasic perception with an initial bright phase and a following dim phase. Type A or Type B masking functions were found when brightness ratings were based on the initial or second perceptual phase, respectively. With increasing practice, Type B masking was reduced and participants reported a shift of criterion content from the second to the initial perceptual phase. Changes in criterion contents might also account for the finding that Type A or Type B masking functions have been found when participants were instructed to respond fast or slow, respectively (Lachter & Durgin, 1999; Lachter, Durgin, & Washington, 2000). According to Lachter and colleagues, fast responses are based on stimulus information that is available briefly after stimulus presentation whereas slow responses are based on stimulus information that is available only at a later stage of processing. Therefore, Type B masking functions on trials with slow responses indicate a failure to retain information over short periods of time (Lachter et al., 2000). Thus, the concept of criterion content predicts individual different masking functions if one assumes individually different predispositions for specific criterion contents. We found that individuals who performed the same perceptual task showed a predisposition to either Type A or Type B masking from the beginning on, and progressively segregated into groups with either Type A or Type B masking functions.

2. General methods

2.1. Participants

Sixteen students (four male) from Göttingen University between 18 and 23 years old participated in Experiments 1 and 2. Ten of them also participated in Experiments 3 and 4. All had normal or corrected-to-normal vision and received partial course credit.

2.2. Tasks

Participants were repeatedly examined in four experiments which employed stimulus sequences exemplified in Fig. 1a. In the target discrimination task participants were to respond as accurate as possible, and without speed stress, to the shape of the target stimulus (square or diamond) with a left or right hand response (Experiments 1, 3, and 4). In the choice reaction time task participants responded to the masking stimulus (square or diamond) with a left or right hand response (Experiment 2).

2.3. Stimuli

The stimuli used throughout the experiments were small filled squares and diamonds (targets) subtending 1.5° of visual angle and bigger framed stimuli (masks) 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 (Fig. 1a and b). All stimuli were black (0.03 cd/m^2) on a light gray background (72.3 cd/m^2) in the center of the screen with durations of 24 ms and 108 ms for targets and masks, respectively. Targets were always presented before the mask with an SOA of 24, 36, 48, 60, 72, or 84 ms. 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). The congruency varied randomly across trials (Fig. 1b). Auditory feedback (1000 Hz, 100 ms) was given on each error response.

2.4. Procedure

The sequence of events was the same for all experiments: Each trial started with a fixation cross for 750 ms followed by the target and then the mask (Fig. 1a). The inter-trial interval varied between 800 ms and 1850 ms following a quasi-exponential distribution. For the target discrimination task 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. The participants pressed the left button upon seeing a square and the right button when seeing a diamond. Participants had to respond within 3 s after mask onset. For the choice reaction time task they were instructed to respond as fast as possible to the outer contour of the mask and to ignore the shape stimulus presented before the mask.

The data of Experiments 1 and 2 was collected across two successive sessions each, and the data of Experiments 3 and 4 across a single session each. Each session was run at 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 ms) were varied pseudo-randomly within each block so that each of the 12 combinations was repeated 4 times in each block and 48 times in each session. In Experiment 4 only two SOAs with 24 ms and 72 ms were employed.

2.5. Data analysis

Discrimination performance for each participant and SOA was assessed by a signal detection analysis resulting in measures of d’. Measures of d’ were calculated for each masking stimulus separately, and averaged across type of masking stimuli (Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2004). However, to facilitate the readability of the figures we report percent correct in the figures below. Perceptual learning was analyzed based on an estimation of the performance in a certain training period by summarizing performance measures across the trials of each quarter of a session (three blocks of experimental trials, 144 trials total). In this way, perceptual learning across two sessions could be captured across eight training periods, constituting the independent variable Practice (T1–T8). The analysis of reaction time (RT) data in Experiment 2 was based on correct trials only; error data was arc-sine-transformed before analysis. RTs on correct trials were sorted for each condition and summarized by trimmed means (10% per participant and condition, Wilcox, 1997). When appropriate, Huyn–Feldt corrected *p*-values are reported. To facilitate readability uncorrected degrees of freedom are reported.

3. Experiment 1

3.1. Results

Fig. 2a shows the performance of each participant as a function of SOA in the second session of Experiment 1. Visual inspection of the data reveals that in ten participants target visibility decreased with increasing SOA reaching a minimum at 60 ms SOA, and it increased with longer SOAs. In contrast, in five participants target visibility increased with increasing SOA across the entire range of SOAs. A single participant (Participant 14) did not show one of these patterns because in this participant target visibility did not change with SOA. Apart from this participant, all other participants either showed clear Type A masking with a minimum in visibility at a SOA of 24 ms, or clear Type B masking with a minimum in visibility at intermediate SOAs.

To classify participants according to their masking functions, we conducted two types of cluster analyzes on the standardized individual masking functions based on the data of Session 2: Agglomerative hierarchical clustering with Euclidean distances as measure of distance and Ward’s linkage method (Ward, 1963), and *k*-means cluster algorithms. Both types of analyzes yielded exactly the same solutions. The two-group solution yielded the highest values in the Calinski–Harabasz-Criterion (Calinski & Harabasz, 1974) with VRC = 34.5 compared to a VRC = 25.4 and VRC = 23.7 for three and four group solutions, respectively. Both, agglomerative and *k*-means clustering revealed the same two clusters: Participant 1, 2, 3, 5, 7, 9, 11, 12, 13, and 16 – who showed Type B masking – were members of one cluster, whereas participant 4, 6, 8, 10, 14, and 15 – who showed Type A masking – were members of the second cluster. Because participant 14 was a member of the same group in both cluster analyzes, we consider this participant a member of the Type A cluster in all following analyzes, although his masking function did not look like a typical Type A masking function. Note that the same pattern of results was found when the data of this participant was excluded.

Fig. 2b shows the effect of Practice across the two sessions of Experiment 1. A 3-way ANOVA with factors Group (Type A vs. Type B), SOA (24–84 ms), and Practice (training periods T1–T8) revealed that Type A observers performed better than Type B observers (main effect of Group: $F(1, 14) = 48.9$, $p < 0.0001$), and that both groups showed different masking functions (Interaction Group × SOA: $F(5, 70) = 41.6$, $p < 0.0001$). Furthermore, there was a clear learning effect across the eight training periods (main effect of Practice: $F(7, 98) = 18.0$, $p < 0.0001$). Most important, however, learning was different for Type A and Type B observers (interaction Group × Practice: $F(7, 98) = 4.35$, $p = 0.001$). This interaction was further modulated by SOA (interaction Group × Practice × SOA: $F(35, 490) = 1.68$, $p = 0.01$).

To assess the differences in learning in more detail, we computed the following pairwise comparisons: For both groups of observers and each level of SOA we compared the performance at T1 with performance at each of the following training

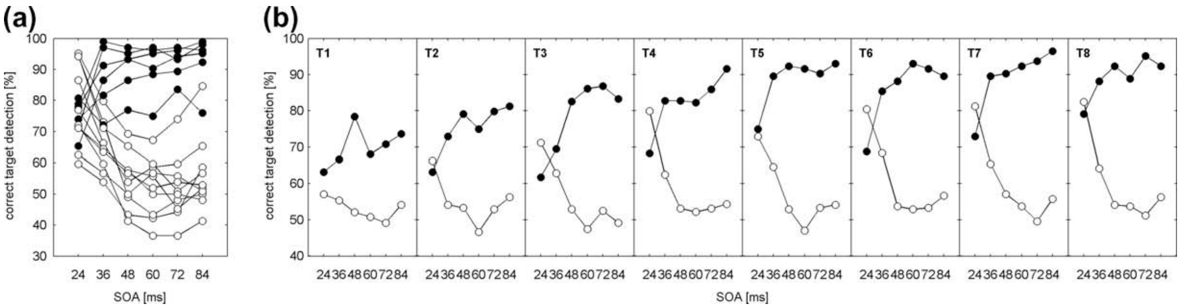

Fig. 2. Results. (a) Individual masking functions of all participants in Experiment 1, Session 2. (b) Development of mean masking functions in Experiment 1 across four quarters of Session 1 (T1–T4) and Session 2 (T5–T8). Filled and open symbols denote Type A and Type B observers, respectively.

periods (i.e., T1 vs. T2, T1 vs. T3, and so on) using Fisher's LSD as a rather liberal test for multiple comparisons (see e.g., Shaffer, 1995). As shown in Fig. 2b, Type A observers' performance was better at T8 than at T1 for all SOAs (all *ps* < 0.01). Interestingly, performance of Type A improved initially in conditions with long SOAs and only later in conditions with short SOAs: With a SOA of 60 ms a significant improvement started already at T3 ($p < 0.001$), with a 72 ms SOA at T2 ($p = 0.05$), and with a 84 ms SOA at T3 ($p = 0.05$). In contrast, with a 24 ms SOA a significant performance improvement did not start before T5 (T2–T4: *ps* > 0.80; T5: $p = 0.02$). With SOAs of 36 ms and 48 ms the first significant improvement was observed at T4 and T5, respectively. On the other hand, Fig. 2b also shows that performance of Type B observers improved initially in conditions with short SOAs. With long SOAs, in contrast, we found no significant improvement during two sessions of practice: With a 24 ms SOA performance improved already from T1 to the next point in time T2 ($p = 0.02$), with a 36 ms SOA performance did not improve before T5 ($p = 0.02$), and with longer SOAs Type B observers' performance did not change during the eight training periods we examined (all *ps* > 0.19).

3.2. Discussion

The retrospective analysis of perceptual learning revealed that target visibility improved with increasing practice at different SOAs in two distinct groups of observers resulting either in Type A or in Type B masking functions. Moreover, evidence for initial perceptual learning was found at different SOAs in the two groups of observers: Performance of Type A observers initially improved with long SOAs whereas performance of Type B observers improved with short SOAs. Overall, Type A observers performed better than Type B observers. This result is at odds with models of backward masking, which predict that Type B masking is generally weaker than Type A masking (Francis, 2003; Francis & Herzog, 2004). However, because the present finding is based on group differences, it is unclear whether this effect results from different performance levels in the two groups of participants or from the underlying mechanisms of backward masking.

As suggested by an anonymous reviewer, there is a possibility that the different masking functions result because the inter-trial-interval (ITI) was too short for at least some participants to prepare the processing of the target or to proceed with a specific processing strategy. Note that the ITI varied randomly between trials with 800 and 1850 ms before the warning stimulus was presented for 750 ms. Thus, there was an interval of 1550–2600 ms from the last response to the next target presentation that could be used for preparatory processes. However, no participant indicated that the time between trials was too short when we asked them in our debriefing procedure after each experimental session. Moreover, additional analyzes of our data did not provide evidence for an effect of ITI: When we compared the performance of the two groups of observers in those 25 percent of the trials with shortest ITIs (mean 847 ms) and those 25 percent of the trials with the longest ITIs (mean 1518 ms) we did not find a main effect of ITI ($F(1, 14) = 1.42$, $p = 0.25$) nor any interaction of ITI and any other independent variable (all *Fs* < 1, *ps* > 0.45). Thus, although we think it is unlikely that the short ITIs contributed to the present findings, it seems reasonable to address this issue in future research.

According to Lachter and Durgin, Type A and Type B masking functions result from fast and slow responses, respectively (Lachter & Durgin, 1999; Lachter et al., 2000). However, an analysis of the RTs of the two groups of observers yielded no difference between mean RTs (973 ms and 913 ms for Type A observers and Type B observers, respectively; $t(14) = 0.64$, $p = 0.54$). To the extent that our paradigm can be compared to Lachter and Durgin's paradigm, following Lachter and Durgin's perspective, one would have to assume that Type A observers retained early stimulus information but Type B observers did not, although there is no difference in response speed between groups. Otherwise, our data provide no evidence for the view that the two types of observers differ in respect of retention failure, because mean RTs of both groups are comparable to those of Lachter and Durgin's participants in slow response conditions (Lachter & Durgin, 1999).

Our practice effects differ from those of previous studies (Hogben & DiLollo, 1984; Ventura, 1980), which reported a reduction of Type B metacontrast masking when practice increased. For instance, in a brightness judgment task, Ventura (1980) initially found clear Type B masking functions that were successively reduced during the course of up to five short practice sessions. This effect has been attributed to a change of criterion content, because participants reported that they changed cues provided by the stimulus on which they based their brightness judgment. In contrast, however, in our participants practice enhanced individual differences in masking functions. This finding suggests that our participants from the beginning on had certain predispositions to either one of two cues, and they had difficulties or were unable to switch between cues. Instead, perceptual learning led to more efficient processing with the preferred cues. Further research is needed to understand the experimental variables which determine whether practice effects abolish or stabilize metacontrast masking functions and whether participants can change criterion content or not.

4. Experiment 2

4.1. Method

To investigate whether the perceptual learning effects found in Experiment 1 generalize across different behavioral tasks, we conducted Experiment 2 to examine the difference in the two groups based on Type A or Type B masking functions in Experiment 1, when an independent task was performed on the same visual stimuli as in Experiment 1. Stimulus conditions remained the same (Fig. 1a and b) but the participants' task changed: In a speeded choice reaction time task participants responded to the shape of the masking stimulus (square or diamond) with a left or right hand response. Each participant was run in two successive sessions. Error feedback was given on each incorrect trial.

4.2. Results and discussion

Overall, mean RT of the two groups of observers did not differ significantly (main effect of Group: $F(1, 14) < 1$, $p > 0.8$). An analysis of the data of each quarter of the two sessions revealed that there was a significant practice effect on mean RTs ($F(7, 98) = 13.18$, $p < 0.0001$) with faster responses in later training periods (475 ms, 460 ms, 458 ms, 455 ms, 429 ms, 432 ms, 429 ms, and 426 ms for T1–T8, respectively). This practice effect did not differ in the two groups of observers as indicated by the non-significant interaction of Group × Practice ($F(7, 98) < 1$, $p > 0.8$).

To determine whether the target stimulus affected the response to the mask, the priming effect was calculated as the mean RT on incongruent trials minus mean RT on congruent trials. Fig. 3 shows that both groups exhibited typical priming effects that increased monotonically with SOA in both groups (e.g., Mattler, 2003; Vorberg et al., 2003). This effect was confirmed by the significant interaction of SOA and Congruency ($F(5, 70) = 43.8$, $p < 0.0001$). The mean slope of the priming function was $s = 1.21$, which did not differ significantly from unity ($t(15) = 1.54$, $p = 0.15$). The priming effect differed between groups as shown by the significant interaction of Group and Congruency ($F(1, 14) = 4.22$, $p = 0.05$), with a slightly larger priming effect in Type A observers (56 ms vs. 38 ms). The priming effect was not modulated by Practice as reflected in the non-significant interactions of Practice with Congruency or any other independent variable (all $Fs < 1$, $ps > 0.70$). Most important, however, although SOA differentially modulated the perception of the effective stimulus in the two groups (Experiment 1), the priming effect was modulated by SOA in both groups in about the same way: The 3-way interaction of Congruency, SOA and Group was not significant ($F(5, 70) = 1.49$, $p = 0.23$). Analysis of choice error rate (mean 2.8%, Table 1) revealed a significant main effect for SOA ($F(5, 70) = 17.53$, $p < 0.001$) and a significant interaction SOA × Congruency ($F(5, 70) = 3.86$, $p < 0.01$) reflecting an increased priming effect with increasing SOA. All other effects did not reach significance (all $F < 1$, $p > 0.5$).

These findings are further evidence for the dissociation between priming effects and the visibility of the effective stimuli (Fehrer & Raab, 1962; Klotz & Neumann, 1999; Mattler, 2003, 2005, 2006; Mattler & Fendrich, 2007; Neumann & Klotz, 1994; Schmidt, 2000, 2002; Vorberg et al., 2003). Most importantly, however, this finding shows that perceptual learning in Experiment 1 was at least somewhat task specific. Therefore, perceptual learning in Experiment 1 did not result in generally modified priming-related processing of the target stimuli in each of the two groups. Instead, perceptual learning improved the processing of specific cues generated by the target-mask sequence that were differentially used by individuals of the two groups to perform the target discrimination task (Ahissar & Hochstein, 1993).

The slope of the priming effects in the speeded choice RT task approached unity, which means that the priming effect increased by about 10 ms when the SOA increased by 10 ms. This replicates previous findings in favour for the view, that the target stimulus activated the corresponding motor response leading to facilitated responses on congruent trials and delayed responses on incongruent trials (Mattler, 2003; Schmidt, 2002; Vorberg et al., 2003). Target induced response activation is also suggested by electrophysiological findings which show target related response activation in the motor cortex

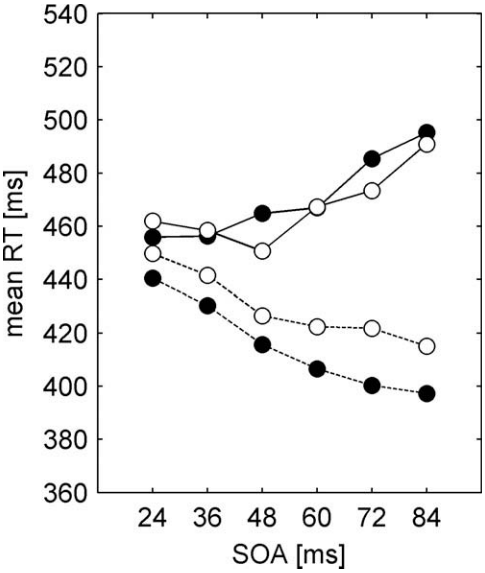

Fig. 3. Mean RT in the choice RT task of Experiment 2 for Type A (filled symbols) and Type B observers (open symbols) on congruent (dashed line) and incongruent trials (solid line).

Table 1
Mean error percentages in Experiment 2.

Prime–mask congruency	Prime–mask SOA (ms)					
	24	36	48	60	72	84
Type A observers						
Congruent	1.6	1.4	0.9	0.7	1.0	0.7
Incongruent	1.9	1.9	2.1	4.2	5.0	13.2
Type B observers						
Congruent	1.3	1.4	1.6	1.7	1.8	1.5
Incongruent	2.2	1.4	2.2	3.8	5.6	8.1

(e.g., Leuthold & Kopp, 1998). Moreover, as demonstrated by the priming effects on accuracy data in Experiment 2, target induced response activation can lead to the execution of incorrect responses (e.g., Mattler, 2003; Vorberg et al., 2003). For instance, an experiment of Vorberg and colleagues (2003) revealed increasing error rates with increasing SOA and up to 60% erroneous responses on trials with incongruent masks. If target stimuli activate the corresponding motor response in speeded choice RT tasks, one could hypothesize that the monotonic increase of prime recognition performance with increasing SOA (Type A masking functions) might also result from target induced response activation if participants are instructed to respond fast. Therefore, target induced response activation might explain previous findings which suggest a relation between masking functions and response speed (Lachter & Durgin, 1999; Lachter et al., 2000). Note, that individual differences in Experiment 1 cannot be accounted for by response activation effects, because both groups of participants responded without speed stress and produced similarly long RTs despite different masking functions.

5. Experiment 3

5.1. Method

Experiment 3 was conducted to test the stability of the perceptual learning effects of Experiment 1. We recruited five participants with Type A masking functions (one participant was no longer available) and five randomly selected participants with Type B masking functions for a repetition of the target discrimination task of Experiment 1. On average, the sessions of Experiment 3 were run 105 days after the second session of Experiment 1 (range: 33–160 days).

5.2. Results and discussion

Fig. 4a and b display the data of the subsample of 10 participants who continued with Experiment 3. To facilitate comparison, Fig. 4a reproduces the data of these participants from the second session of Experiment 1, and Fig. 4b shows their performance as a function of SOA in Experiment 3. Experiment 3 replicated the findings of Experiment 1 as revealed by a 2 × 6 ANOVA with Group and SOA as independent variables: Type A observers performed better than Type B observers (main effect Group: $F(1, 8) = 152.52$, $p < 0.0001$), and these differences were modulated by SOA, as revealed by the significant interaction of Group × SOA ($F(5, 40) = 31.0$, $p < 0.0001$). The main effect for SOA did not reach significance ($F(5, 40) = 1.15$, $p > 0.30$).

To compare the performance in Experiments 1 and 3 we conducted a second ANOVA with Time (Experiment 1 vs. Experiment 3) and SOA as within-subjects-factors, and Group as between subjects-factor. Like in the analysis of the data

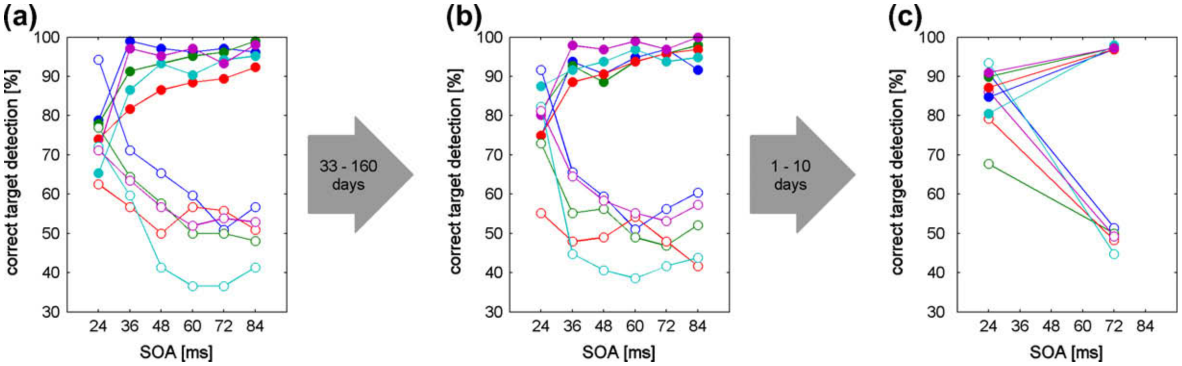

Fig. 4. (a) Individual masking functions in Experiment 1, Session 2 for the remaining 10 participants who took part in Experiment 3. (b) Individual masking functions in Experiment 3, 33–160 days later. (c) Individual masking functions in Experiment 4 with fixed SOAs for six blocks of trials following 1–10 days after Experiment 3. Color codes different participants. Filled and open symbols denote Type A and Type B observers, respectively.

of Experiment 3 alone, the main effect of Group ($F(1, 8) = 140.9$, $p < 0.0001$) and the interaction of Group × SOA was significant ($F(5, 40) = 38.9$, $p < 0.0001$), whereas no main effect for SOA was obtained ($F(5, 40) = 0.87$, $p = 0.48$). Most importantly, however, factor Time did not yield any significant main effect or interaction (always $F < 2.0$, $p > 0.16$), indicating a certain stability of participants' performance during the period between Experiment 1 and Experiment 3 (compare Fig. 4a and b). Thus, the present learning effects seem to remain largely unchanged between experiments thus indicating that learning this perceptual task results in masking functions of a certain Type and level of expression that persist across a relatively long period of time.

6. Experiment 4

A final test of the stability of individual differences was established in Experiment 4, which examined whether participants' perceptual performance improves if they are shown only trials with that SOA at which they had performed poor in previous sessions. We presented an entire half of the session with a constant short SOA of 24 ms and the other half of the session with a constant long SOA of 72 ms. These SOAs were chosen because they discriminated best between the two groups of observers. The short SOA was relatively easy for Type B observers but relatively difficult for Type A observers, the long SOA was relatively easy for Type A observers but relatively difficult for Type B observers. Six blocks with difficult trials were presented in the first half of the experiment followed by six blocks with easy trials in each group. Again, feedback was given on every error trial. For the different participants this session followed 1–10 days after their last session of Experiment 3.

6.1. Results

The findings replicated those of Experiments 1 and 3 (see Fig. 4c): The two groups of observers performed differently at the two levels of SOA (interaction Group × SOA: $F(1, 8) = 89.6$, $p < 0.0001$) with Type A observers showing a better overall performance than Type B observers (main effect Group: $F(1, 8) = 139.3$, $p < 0.0001$). Furthermore, we found a significant main effect of SOA ($F(1, 8) = 8.11$, $p = 0.02$).

To examine whether participants' performance improved due to the blocked presentation of one of two SOAs, we computed orthogonal linear contrasts between Experiment 3 and Experiment 4 for each group at each SOA. Type A observers did not improve significantly with the short SOA ($F(1, 8) = 2.44$, $p = 0.16$) but did improve with the long SOA ($F(1, 8) = 13.39$, $p = 0.006$). Type B observers improved only with the short SOA ($F(1, 8) = 6.13$, $p = 0.03$) but not with the long SOA ($F(1, 8) = 0.03$, $p = 0.87$).

6.2. Discussion

Experiment 4 provides further evidence for the stability of the effects of perceptual leaning in previous sessions. Additional evidence for further improvements was found primarily in those SOA conditions that were easy for the respective group of observers but not in their difficult SOA conditions. Thus, participants further improved in conditions in which they performed well before, but did not improve in previously poor conditions. Again, no evidence for a reduction in metacontrast masking due to practice could be found. In contrast to findings of Ventura (1980) and Hogben and DiLollo (1984), which suggest that participants shifted the criterion content, our results suggest that participants were biased to use particular cues and they had difficulties using cues that they had not been using before, although other participants were able to use these other cues.

7. General discussion

Participants who practiced a target discrimination task in a metacontrast masking paradigm, spontaneously and progressively segregated into groups with either Type A or Type B masking functions. A retrospective analysis of the data from two sessions revealed that individuals who showed Type A and Type B masking functions at the end of the sessions differed already in the first three blocks of the experiment, which suggests that they had predispositions to either one of the two types of perceptual responding acquired in their previous lives. Practice enhanced group differences mainly because performance in the two groups improved in different SOA conditions. These effects of perceptual learning were at least somewhat task specific because the effect of SOA did not vary across groups when participants responded to the masking stimulus in a speeded choice RT task.

Two additional experiments revealed that the perceptual learning effects of the initial experiment remained relatively stable: Within groups, the masking functions did not differ in a follow-up test about 3 months later. Finally, even when participants performed the target discrimination task during 288 trials with the stimulus conditions that were most difficult for them, performance did not improve despite single trial feedback. On the other hand, when they performed the task with only those stimulus conditions that were easy for them, a further performance increase was obtained. These results show that participants have considerable difficulties switching from their preferred type of processing to become a different type of observer. To the best of our knowledge, this is the first demonstration showing that two types of metacontrast masking functions can be based on individual differences in learning despite identical learning conditions.

Individual differences have been a vexing problem in perceptual learning (Fahle & Poggio, 2002) and they have been deemed undesirable complications in backward masking (Marcel, 1983; however, see Mattler, 2003, who took advantage of individual differences). Weisstein, Jurkens, & Onderisin (1970) and Weisstein (1972) also reported considerable variation in the SOA at which masking was strongest and emphasized the importance of individual data for fitting masking functions to models. The differences in the two groups of observers reported in the present study are unlikely to be due to motivational differences, because both groups improved with practice in some stimulus conditions. However, a few studies related individual differences in perceptual tasks to measures of intelligence (for a review see Nettelbeck, 2001). Therefore, we cannot exclude the possibility that differences in general cognitive styles, like e.g., field dependence, levelers vs. sharpener, contribute to the differences reported here. This issue has to be dealt with in future research.

Within the context of the Reverse Hierarchy Theory (RHT), we suspect that there were initial differences between individuals either directly in the neural response involving neuroanatomically early levels of stimulus processing, or in later processes related to the attentional or response-related selection of an adequate neural level of processing. Such a gradual initial difference between individuals could lead to the spontaneous development of a dichotomous difference between observers through some kind of "winner takes all" algorithm that exaggerates the initial bias. The categorical difference between observers, as reflected in the two distinct masking functions could then result as suggested by RHT. Ahissar and Hochstein (1993, 1997) did not explicitly discuss masking functions. However, according to the principles of their theory as we use them here two types of masking functions can result if there is a choice between two types of cues that are processed at neural levels that have sufficient plasticity to enable perceptual learning. Thus, we assume that due to an initial bias or a predisposition acquired earlier in life participants selected one of two neural levels and due to perceptual learning at the selected levels of processing they developed either to strong Type A or strong Type B observers. This view is consistent with our finding that the difference between masking functions seem to occur within the initial three blocks of trials, indicating that participants selected the neural levels of processing in the perceptual hierarchy very early before performance was further modulated by perceptual learning. To examine the initial plasticity of participants' visual system, it would be interesting to ask experienced observers how they make their judgments and then see whether naïve participants can be trained to learn a given cue and produce Type A or Type B masking functions, or whether Type A observers change to Type B observers (and vice versa) when they use the corresponding criteria. If the two types of processing which lead to two types of masking functions emerge spontaneously, participants should have difficulties to learn both cues with the same ease.

Metacontrast masking has been used previously in priming studies to demonstrate the processing of unconscious stimuli (e.g., Klotz & Neumann, 1999; Mattler, 2003; Neumann & Klotz, 1994; Vorberg et al., 2003). The present study provides new evidence for the processing of unconscious visual stimuli by showing virtually the same priming effects in participants who have learned to discriminate the targets (primes) with either Type A or Type B masking functions. These findings show that the practice effect related to the processing of the target (prime) stimuli did not modulate the effects of these stimuli in the speeded choice RT task. Therefore, it could be assumed that the functioning of neural levels of target (prime) processing that was changed in the course of the target discrimination task did not contribute to the priming effect of these stimuli in the choice RT task. This view is consistent with the distinction of different visual pathways (Milner & Goodale, 1995) as well as with the idea that conscious perception crucially depends on recurrent processing (e.g., Lamme & Roelfsema, 2000). According to both views, there are common visual processes and specific visual processes for conscious perception and motor priming. From this perspective, it seems likely that perceptual learning modulates processing of the target stimuli at a neural level that is specific for conscious perception but not necessary for motor priming. In light of a recent study, which suggests that processing in V1 is crucial for both conscious perception and unconscious priming (Sack, van der Mark, Schuhmann, Schwarzbach, & Goebel, 2009), we assume it most likely that perceptual learning in our case occurred at neuroanatomically levels later than V1.

The priming effect did not change across two sessions of practice. On the one hand, this absence of practice effects might suggest that the neural levels of target (prime) processing operate effectively already after little training in the choice RT task. On the other hand, the absence of practice effects might also suggest that the priming effect results from levels of target (prime) processing that are insensitive to practice-related changes. However, no practice effects on the priming effect are consistent with RHT, which assumes that perceptual learning requires an initial top-down selection of adequate levels of processing. When the relevant information is provided by such an easily visible stimulus as the mask in the present choice RT task, RHT predicts that perceptual learning occurs only at the neural level of mask processing. Therefore, the processing of the mask should change with practice but the priming effect caused by the target (prime) should not change with practice. Our data is consistent with both of these predictions.

Our findings have potentially important implications for the understanding of conscious perception. We found clear individual differences in the target discrimination task that clustered into two groups of observers. For instance, high levels of accuracy above 90% correct were obtained in Type A observers at long SOAs and low levels of accuracy below 60% correct in Type B observers. These findings suggest that the performance difference in the two groups of observers corresponds to a difference in the subjective experience of the stimulus sequence in the two groups. The data show that individuals differ in how they use cues provided by the stimulus sequence and that this difference could be a basis for differences in the conscious experiences of the stimuli.

Moreover, since performance was modulated by perceptual learning, we might conclude that subjective experience of visual stimuli is modulated by perceptual learning. This interpretation is consistent with current theories of conscious perception like the global-workspace theory (Baars, 1988; Dehaene, Kerszberg, & Changeux, 1998). According to this view, one necessary – although not sufficient – condition for the emergence of conscious experience is a certain neural activity with a certain duration which enables information to become available to a broad range of neural processes probably including those in prefrontal cortex (for a review see Maia & Cleeremans, 2005). On this background, two groups of observers with exaggerated individual differences result after sufficient perceptual learning because there are two types of neural signals which can be enhanced by participants attendance and perceptual learning leading to an increased stability in time or strength of the stimulus representation which is necessary to become available for other interpretative processes like recurrent interactions which might enable availability of the stimulus representation in the global workspace (Cleeremans, 2007). Unfortunately, in the present study we have not gathered subjective reports to test this hypothesis. Preliminary data of a recent study, however, indeed suggest different subjective experiences in Type A and Type B observers. Therefore, we think the present phenomenon might serve as a tool to study the relation between perceptual learning and conscious perception.

In conclusion, we think these findings provide new evidence that might help to distinguish between models of metacontrast masking (Breitmeyer & Ögmen, 2000; Ishikawa et al., 2006) and stress the possibility that there may be no single universal model of the processes underlying masking. Moreover, the results contribute to the understanding of the priming effects of unconscious visual stimuli and to the role of conscious perception in cognition and action (Mattler, 2003). Beyond this, the phenomenon might be useful as a model for the study of neural mechanisms that are involved in the development of individual differences. Further research is need to examine the initial bias that directs perceptual learning either to Type A or Type B performance. Whether this initial bias is due to more general cognitive or attentional styles is subject of research currently under way.

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