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Revisiting the metacontrast dissociation: Comparing sensitivity across different measures and tasks

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Revisiting the metacontrast dissociation: Comparing sensitivity across different measures and tasks

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In the metacontrast dissociation procedure, presenting a masked shape prime prior to a visible shape target leads to reaction-time effects of the prime in an indirect measure, although participants cannot consciously detect prime shapes in a direct measure (Klotz & Neumann, 1999). This has been taken as evidence for the processing of unconscious input. The results of the present metacontrast dissociation study indicate that although participants are unable to consciously report the shape of the prime, they can consciously perceive motion between masked primes and visible targets in a hybrid direct/indirect measure (Experiments 1 and 3). This indicates that former tests did not provide an exhaustive measure for residual conscious perception of the prime in the metacontrast dissociation procedure. Further tests, however, reveal that residual motion perception cannot account for performance in the indirect measure (Experiments 2 and 3). Although the results thus leave the conception of processing of unconscious input intact, they may prompt a revision of its criteria.

Keywords: Subliminal perception; Visual motion; Visual masking.

Until relatively recently, many authors were sceptical about the possibility that processing of visual input can occur at unconscious levels (Eriksen, 1960; Holender, 1986). The situation gradually changed with the discovery of spared visual processing capabilities in the absence of visual conscious perception in several neurophysiological case reports (Goodale, Milner, Jacobson, & Carey, 1991; Weiskrantz, Warrington, Sanders, & Marshall, 1974) and with the refinement of experimental techniques allowing the demonstration of similar dissociations between conscious vision and unconscious processing faculties in healthy, unimpaired observers (Bridgeman, Lewis, Heit, & Nagle, 1979; Fehrer & Raab, 1962; Neumann & Klotz, 1994; Wolff, 1989).

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One widely used experimental technique for demonstrating unconscious visual processing in healthy participants is the masked priming procedure (Marcel, 1983). In the masked priming procedure, visual masking is used to block conscious access to a visual prime stimulus. Invisibility of the prime is demonstrated in a prime discrimination or detection task. Then, processing of the very same prime is demonstrated by its priming influence on the response to a clearly visible target stimulus during a target-response task. Performance in the prime detection task provides the so-called "direct measure" because this measure reflects the processing of the prime directly, by prime visibility (cf. Reingold & Merikle, 1988). By contrast, the target-response task is called the "indirect measure" because it reflects the processing of the prime indirectly, by way of its priming influence on target responses (but see Klotz & Neumann, 1999).

In the masked priming procedure, the conclusion that processing of the prime reflected in the indirect measure occurs at unconscious levels is only justified if (a) the indirect measure is more sensitive than the direct measure for the information contained in the prime, and (b) the direct measure exhaustively measures residual conscious perception of the prime (Reingold & Merikle, 1988, 1990; Schmidt & Vorberg, 2006). One of the most convincing confirmations of an unconscious masked priming effect with an exhaustive direct measure was given by the so-called metacontrast dissociation (cf. Ansorge, Klotz, & Neumann, 1998; Klotz & Neumann, 1999; Klotz & Wolff, 1995; Neumann & Klotz, 1994; but see Schmidt & Vorberg, 2006, and the discussion below for alternative views). In their landmark study, Klotz and Neumann (1999; see also Experiment 1 of Neumann & Klotz, 1994) presented a pair of clearly visible geometric stimuli in each trial. One of these stimuli was a square, and the other one a diamond (see Figure 1). With a diamond on the right of fixation, a square was shown on the left of fixation, and vice versa. In their direct and indirect-measure tasks, both of these clearly visible figures served as backward masks, diminishing the visibility of the preceding primes (see below). In the indirect-measure task, one stimulus of this pair of clearly visible shapes additionally served as a target, and participants had to respond to its position (left or right of fixation). Half of the participants had to respond to the square's position, the other half to the diamond's position. Let us assume that a participant had to respond to the square's position. Then, with a square on the right, she had to give a right-hand key press, and with a square on the left she had to give a left-hand key press.

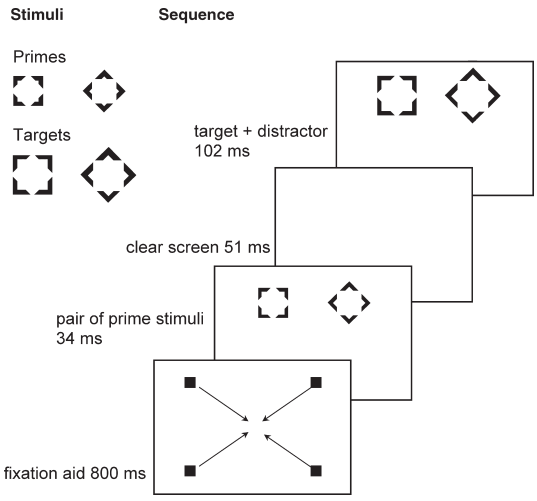

Figure 1. *Depicted are the different stimuli on the left and an example of the stimulus sequence within a trial on the right. Left: In Experiment 1, targets were either squares or diamonds. Right: Depicted is the sequence of stimuli (starting from the bottom) in a congruent trial, with prime and target above fixation.*

Unknown to the participants, smaller replicas of target and mask figures were presented as primes with a brief stimulus onset asynchrony (SOA) prior to the surrounding targets (which also served as masks for the primes). The visibility of the primes was severely reduced by metacontrast masking, a form of backward masking by spatially adjacent but nonoverlapping stimuli, in the current case by the target and the second mask or distractor (cf. Breitmeyer, 1984; Breitmeyer & Ogmen, 2006). Crucially, Klotz and Neumann (1999) varied the amount of prime–target congruence. Under *congruent conditions*, the pair of primes consisted of one small diamond and one small square

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that were presented at the same respective positions as the temporally trailing target and mask. For instance, with a diamond-shaped prime on the right and a square-shaped prime on the left, the trailing target–mask display also consisted of a prime-surrounding diamond on the right and a prime-surrounding square on the left. Under *incongruent conditions*, the pair of primes consisted of one small diamond and one small square presented at positions that were exchanged relative to those of the temporally trailing target and mask. For instance, with a diamond-shaped prime on the right and a square-shaped prime on the left, the trailing target–mask display consisted of a diamond-shaped stimulus on the left and a square-shaped stimulus on the right. In a third, neutral condition, the prime display consisted of two non-target-like figures: If a participant had to respond to square targets, a neutral prime display consisted of two diamonds, and if a participant had to respond to diamond targets, a neutral prime display consisted of two squares.

Klotz and Neumann (1999) expected and found response time (RT) effects reflecting the processing of the masked primes in their indirect-measure task. Their expectations concerning performance in the indirect-measure task were based on the assumptions of the direct parameter specification (DPS) concept. According to the DPS theory, unconscious visual input can be used to specify free parameters of overt responses at least once an action plan has been set up in advance of the visual input (Neumann, 1989, 1990). As a consequence, a masked prime with a target-like shape should be able to specify a free motor parameter and to activate a response in the target–response task, its invisibility notwithstanding. In detail, in the congruent condition, in which the masked target-like prime is presented at the same side as the target, response facilitation was expected, because the prime should activate the same response as is subsequently required for the target. In the incongruent condition, in which the masked target-like prime is presented on the side opposite to that of the target, response interference was expected, because the prime should activate the alternative response relative to the correct one subsequently required for the target. Both facilitation and interference were expected to be evident in comparison to performance in the neutral condition, in which no target-like prime is presented in the priming display, such that the prime could not activate a response. These predictions of the DPS concept were nicely borne out by the results (Klotz & Neumann, 1999).

What made the study outstanding was neither the size nor the reliability of the priming effect reflected in the indirect measure but the scrutiny with which residual conscious perception of the primes was ruled out in the direct measure. Klotz and Neumann (1999) were well aware of the possibility that each particular direct-measure task has advantages as well as shortcomings if used with the intention to exhaustively measure residual conscious perception. So they eventually used a large number of diverse direct-measure tasks.

To start with, an exhaustive direct-measure task requires that the direct- and indirect-measure tasks must be as similar as possible (Reingold & Merikle, 1988, 1990). Accordingly, Klotz and Neumann (1999) used the same stimuli, the same responses, and the same number of stimulus–response alternatives for their direct and indirect measures, with the major difference between the two tasks being the task-relevance of the stimuli: Participants had to detect prime figures in the direct-measure task but had to report target positions in the indirect-measure task. For the direct measure, participants had to judge in each trial whether a target-like prime was present or not, requiring a "yes" response in congruent and incongruent trials but a "no" response in neutral trials.

As direct-measure tasks Klotz and Neumann (1999) used prime detection under conditions with (a) feedback informing participants about whether their actual judgement had been or had not been correct, (b) direct- and indirect-measure tasks intermixed in a single block, (c) direct- and indirect-measure tasks performed in separate blocks, (d) direct- and indirect-measure tasks successively performed in each trial, (e) highly motivating incentives for correct performance allowing participants to earn up to $35 an

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hour if their performance was optimal in the direct-measure task, (f) speeded judgements, and (g) judgements given at leisure.

Moreover, for the direct measure, individual average correctness of performance was converted into the most sensitive index, d' (Green & Swets, 1966) and d_s (Treisman, 1977). d' and d_s indices are independent of the participant's response bias toward giving a yes response because the indices are both computed as difference scores of z-transformed probabilities of yes responses under conditions in which a signal (here, a target-like prime) was presented minus z-transformed probabilities of yes responses under conditions in which no signal (here, no target-like prime) was presented. Despite all these efforts to unveil residual conscious perception of the primes in the direct measure, performance in all experiments (and across experiments) of Klotz and Neumann's (1999) study was at chance levels—that is, d' and d_s were not statistically different from zero, indicating that participants did not see the discriminating shape features of the masked primes at all. Together, the invisibility of the masked prime shapes as reflected in the direct measure and the evidence for the processing of the very same prime shapes as reflected in the indirect measure, constituted (one variant of) the so-called metacontrast dissociation. Additionally, it should be noted that the dissociation could not be attributed to the use of different metrics for the direct measure than for the indirect measure because the same dissociation was found if RT data of the indirect measure were transformed into d_s indices, too (Klotz & Neumann, 1999).

After the original report (Klotz & Neumann, 1999; Experiment 1 of Neumann & Klotz, 1994), numerous replications of the metacontrast dissociation were published. Several replications used different prime, mask, and target stimuli, so that the arguments and tests developed in the present study do not directly apply to these alternative demonstrations (cf. Ansorge, 2003, Exp. 1; Ansorge, 2004; Ansorge & Heumann, 2006; Ansorge & Neumann, 2005; Neumann & Klotz, 1994, Exps. 2–5; Schmidt, 2002; Schmidt, Niehaus, & Nagel, 2006; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003), but others used more or less similar stimuli and experimental procedures to those of Klotz and Neumann (e.g., Ansorge, 2003, Exp. 3; Breitmeyer, Ro, & Singhal, 2004; Eimer, 1999; Jaśkowski & Ślósarek, 2007; Jaśkowski, Van der Lubbe, Schlotterbeck, & Verleger, 2002; Mattler, 2003; Scharlau & Ansorge, 2003; Scharlau, Ansorge, & Horstmann, 2006; Scharlau & Neumann, 2003).

Despite its popularity and widespread use, however, the metacontrast dissociation procedure might not be such an airtight demonstration of unconscious processing of visual input as it appeared to be. At least two arguments raise doubt that the direct measure of the metacontrast dissociation has indeed been exhaustive. First, there are examples in the literature that features of a masked prime can be consciously perceived as features of the mask or as features of a joint percept of both prime and mask. As early as 1935, Heinz Werner observed that features of a test stimulus presented prior to a metacontrast mask were falsely perceived as being part of the temporally trailing mask. Related observations termed "inheritance" (of test stimulus or prime features to the mask) have recently supported Werner's basic observations (Herzog & Koch, 2001; Otto, Ogmen, & Herzog, 2006). The particular feature that might be perceived under conditions of the metacontrast dissociation procedure as described above is the kind of motion created by the interplay of prime and mask. In incongruent conditions, prime and target shapes presented in succession could create the percept of a rotating (and expanding) stimulus (e.g., a small diamond prime rotating into a larger square mask), whereas in congruent conditions, successive prime and target shapes could create the percept of an expanding stimulus without rotation (e.g., a small diamond prime expanding into a larger diamond mask). This possibility is even more likely in light of the finding that perception of motion can occur without concomitant object perception (Wertheimer, 1912) and that motion perception under backward masking conditions can escape the masking effect (Ansorge, Breitmeyer,

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& Becker, 2007; Kolers, 1963). In fact, some investigators (e.g., Breitmeyer & Ogmen, 2000, 2006) have applied one and the same model to account for metacontrast masking as well as for the deblurring of moving objects, allowing for the perception of (a) visual motion and (b) the simultaneously occurring suppression of contours (Puroshothaman, Ogmen, Chen, & Bedell, 1998). Therefore, on empirical and theoretical grounds, we can hypothesize that participants might have a capacity to consciously perceive traces of the masked prime in the form of different motion directions (more vs. less rotation). Note also that comparing different direct measures' sensitivities for different visual features (i.e., motion and shape in the current experiments) is a relevant research topic in its own right: The conclusions that can be derived from comparing the different direct measures are in fact completely independent from the particular theory (DPS theory in the current experiments) that is considered to account for the sensitivity of the indirect measure.

Secondly, in this context, it is noteworthy that it is possible that the direct-measure task in the metacontrast dissociation that was used by Klotz and Neumann (1999) may have led participants astray. Participants might have failed to use different perceived motion directions to infer the kind of prime shape that was being used in a trial because their task was to detect prime displays with a target-like shape prime and, thus, to discriminate between prime displays with a target-like prime and prime displays without such a prime. This type of judgement requires that displays that were most dissimilar with respect to the putative perceived motion directions—congruent displays consisting of nonrotating prime–mask sequences on the left and on the right and incongruent displays consisting of rotating prime–mask sequences on the left and on the right—had to be classified as belonging to the same yes-response class, whereas displays most equivocal with respect to their contained motion direction information—neutral displays consisting of one rotating and one nonrotating prime–mask sequence—had to be classified as belonging to the alternative no-response class. Under these conditions, the participants' naïve use of perceived motion for inferring the presence of a target-like prime shape could have artificially created chance-level performance in the direct measure. For instance, assume that a participant used the absence of rotation for inferring that a target-like prime shape was being displayed and used the presence of rotation for inferring that no target-like prime shape was being displayed. This participant would have correctly responded with "yes" in half of the trials with a signal (the congruent trials) but would have incorrectly responded with "no" in the other half of the signal trials (the incongruent trials). Using the same motion feature of rotation for her judgements in neutral trials naturally would have led to equal probabilities of yes and no responses under neutral conditions too, because neutral displays contained the rotating and nonrotating prime–target sequences in exactly similar amounts. Thus, a residual ability to consciously perceive rotation that existed in incongruent but not in congruent conditions might have escaped the direct measure used by Klotz and Neumann, whereas any direct measure requiring discrimination between congruent and incongruent trials would be a more exhaustive one.

EXPERIMENT 1

Experiment 1 seeks to compare the participants' sensitivity for the processing of masked prime stimulus information by three different measures: one indirect, one direct, and a third one lying between a direct and an indirect measure. For indirect measure [a], we used a masked priming procedure. As a direct measure, we used a prime shape detection task [b]. As a hybrid measure we instated a rotation detection task [c]. This measure is half-way in between a direct and an indirect measure because it requires participants to take into account both perceived prime and perceived mask stimuli.

Altogether, we used three different criteria for testing whether performance in indirect measure [a] reflected processing of unconscious or subliminal input. The first criterion is a performance of

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$d' = 0$ in the direct-measure task [b], and measure [c]. If participants cannot perceive (traces) of the prime, they should be at chance level if the task is to tell trials with a response-relevant prime from trials without a prime [b] or if the task is to tell trials with rotation from trials without rotation [c].

The second criterion is the comparison of indirect measure [a] with either direct measure [b] or measure [c]. According to Reingold and Merikle (1988, 1990), the $d' = 0$ criterion is too conservative in that it assumes that all processing at levels with $d' > 0$ in the direct measure is conscious and, thus, puts all the burden of proof on the side of the hypothesis that visual processing also occurs at unconscious levels. Reingold and Merikle therefore suggested using a comparison of d' values derived from the direct-measure task to those from an indirect-measure task as a less biased criterion for establishing unconscious processing. If the indirect measure, [a], indeed reflects processing of unconscious input, the indirect measure, [a], should exceed the direct measure, [b], $d'(a) > d'(b)$, and measure [c], $d'(a) > d'(c)$.

The third criterion that we used is a test of the significance of the correlation of the indirect measure with the direct measure, [b], or measure [c] (cf. Breitmeyer, Ogmen, Ramon, & Chen, 2005; Greenwald, Draine, & Abrams, 1996; Naccache & Dehaene, 2001). If it is true that visibility (reflected in the direct measure, [b], or measure [c]) of a particular feature of the masked prime accounts for the indirect measure, [a], performance in the indirect measure, [a], should be proportional to performance in the direct measure, [b], or that in measure [c]: The better the visibility of the prime (reflected in the d' values of the direct measure or of measure [c]), the larger the RT effect of the prime (reflected in the d' values derived from the indirect-measure task, [a]) should be. Thus, an effect of the primes that is due to the perception of the masked primes should lead to a significant correlation between direct and indirect measures, whereas dissociation between visibility and processing of the masked primes allows for nonsignificant correlations between direct and indirect measures.

The expected outcomes were as follows. Based on the assumptions of the DPS concept, masked primes should activate responses corresponding to the respective shape/location information contained in them. Therefore, masked priming effects were expected in the indirect measure, [a]. Mean RT (and possibly the average percentage of errors) was expected to be lower under congruent than under neutral and incongruent conditions and under neutral than under incongruent conditions.

Based on previous findings with the metacontrast dissociation procedure, if it is true that conscious perception of the masked primes' contours is completely blocked, we expected that participants cannot detect target-like shape primes. We therefore expected a $d' = 0$ in the direct measure, [b]. However, comparing prime detection performance in the direct measure, [b], by pitting neutral against incongruent conditions or congruent against incongruent conditions might also yield $d' > 0$ (better than chance performance) if hit rates in congruent and incongruent conditions differ: Participants might be able to detect rotation and use it consistently for their shape judgements, too. For instance, seeing no rotation, participants might infer that the masked prime had the same shape as the target and respond "yes", whereas seeing rotation, they might conclude that the masked prime's shape differed from that of the target and respond "no".

Based on the observation that motion perception can escape influences of backward masking, we expected that measure [c], rotation detection, might render above-chance performance (i.e., $d' > 0$). Participants might be able to more frequently perceive visual rotation under incongruent than neutral conditions, under incongruent than congruent conditions, and under neutral than congruent conditions.

The expected capacity to consciously perceive motion under masked priming conditions in the metacontrast dissociation and, thus, the predicted significant d' values in measure [c] notwithstanding, if it is true that (part of) the masked

priming effect in the indirect measure, [a], reflects processing of unconscious visual input, the indirect measure, [a], might at least be more sensitive for the information contained in the masked primes and, therefore, might yield a larger average d' value than would a second sensitive direct measure, [c]. Likewise, if it is true that (part of) the masked priming effect in the indirect measure, [a], reflected processing of unconscious visual input, amounts of RT priming effects reflected in d' values of the indirect measure, [a], should be uncorrelated with the amounts of prime visibility reflected in d' values of even the second measure, [c], which was expected to yield above-chance performance.

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Method

Participants

A total of 34 volunteers (18 female, 16 male), most of them students at Bielefeld University, with a mean age of 28 years, participated in Experiment 1. A total of 2 had to be excluded because they did not show up for the detection task. In both experiments, all participants had normal or corrected-to-normal visual acuity and received €6 per hour for participation.

Apparatus, stimuli, and procedure

These were as similar as possible to those used by Klotz and Neumann (1999; see also Figure 1), except for minor differences. (The values of the original study are noted in parentheses in the following text where the present procedure deviated from that of Klotz & Neumann, 1999.) The stimuli were displayed in dark, with <1 cd/m^2 (original: 0.5 cd/m^2), on a bright background, with 78 cd/m^2 (original: 108 cd/m^2). In each trial, a dynamic fixation aid was used to guide the attention of the participants to the screen centre. It consisted of four small black boxes presented in the corners of the display. These boxes moved on diagonal trajectories to the screen centre, where they merged, and disappeared. Next, a pair of stimuli consisting of a target-shaped prime plus a distractor-shaped stimulus (congruent and incongruent conditions) or two distractor-shaped stimuli (neutral condition) was presented for 34 ms (original: 30 ms), followed by a blank interval of 51 ms (original: 45 ms), and a target–distractor display, consisting of a diamond and a square for 102 ms (original: 90 ms). Pairs of stimuli were horizontally aligned and were presented with an eccentricity of 3° above or below fixation. In the target–distractor display, the outer distance between the square and the diamond was 4.3°. The target-shaped prime and the distractor-shaped prime that were presented in advance of the target and the distractor were smaller replicas of the target-sized and the distractor-sized diamonds and squares. The outer contours of the primes fitted exactly into the inner contours of the surrounding target and distractor, thus allowing for metacontrast masking of the primes by the target–distractor pair.

In each target display, the square was unforeseeable right or left of fixation, and the diamond was shown on the opposite side. The diamond was on the right if the square was on the left, and the diamond was on the left if the square was on the right. In half of the trials, the pair of smaller, preceding primes contained a target-shaped prime. This prime was equally likely at the same position as the upcoming target (congruent condition) and on the side opposite to the upcoming target (incongruent condition). The other half of the trials was the neutral condition, with two distractor-shaped primes preceding the target–distractor display. The intertrial interval was 3 s.

In the indirect-measure task, all of the participants responded to the position of a predefined shape in the target–distractor display. For half of the participants the target was the square, and for the other half of the participants it was the diamond. In all conditions, a left target required a left-hand key press, and a right target required a right-hand key press. Participants had to respond as quickly as possible, while keeping their error rate low.

In the second measure task, half of the participants (Group A) got the shape-detection task (here the direct measure, [b]) that was used by Klotz and Neumann (1999). These participants

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had to detect whether the target-preceding pair of masked stimuli contained a target-shaped prime or not. This task required a yes response in congruent and incongruent trials and a no response in neutral trials. The other half of the participants (Group B) got a rotation detection task (here measure [c]). They had to indicate whether they saw a rotating stimulus or not. This task required a yes response in incongruent and in neutral conditions, because even in the neutral trials the stimulus sequence consisting of a distractor-shaped prime presented prior to and at the position of the target could have been being perceived as rotating. The congruent condition required a no response. The particular judgement rule mapping yes and no responses to left and right hands in a prevailing trial was determined by written instructions on the screen that were shown only after the target–distractor display to prevent the possibility that DPS could have contributed to the performance in the direct measure and in the hybrid measure [c] (cf. Neumann & Klotz, 1994, Exp. 4). In each trial of both the direct-measure task, [b], and measure [c], participants had to judge within 10 s. Accuracy of the judgements was emphasized over judgement speed.

In the blocks with the indirect-measure task, [a], and the measure tasks, [b] and [c], each of the combinations that resulted from a complete crossing of two positions of the target shape (left vs. right) by two priming conditions (target-shaped prime plus distractor-shaped prime, congruent and incongruent condition vs. two distractor-shaped primes) by two stimulus positions (above vs. below fixation) was repeated 24 times, leading to 384 trials. Of all trials, 50% were neutral, 25% were congruent, and 25% were incongruent trials. Together with practice trials, prior to each block, participants took 2 hours to complete all four tasks during two separate sessions.

Analysis

For the computation of direct measure [b] and measure [c], for each participant individual hit rates (i.e., rates of yes responses in congruent and/or incongruent trials of Task [b] and in neutral and/or incongruent trials of Task [c]) and rates of false alarms (i.e., rates of yes responses in neutral trials of Task [b] and in congruent trials of Task [c]) were *z*-transformed (Green & Swets, 1966; Macmillan & Creelman, 2005). For the indirect measure, separately for each participant, the median of all correct RTs below 1,000 ms was computed. Next, rates of incongruent responses above the median RT and rates of neutral (or congruent) trials above the median RT were computed as analogues of hit rates and false alarm rates, respectively. (Note that this procedure yields positive d' values under incongruent conditions, for which Klotz & Neumann, 1999, reported negative d' values because they used RTs $<$ median RT as hits. The different procedures are inconsequential for the power of the resulting indices to illuminate detection abilities.)

Separately for each participant and each of the three tasks, *z*-transformed false-alarm rates were subtracted from *z*-transformed hit rates to get three to four d' indices per participant and task: d' with performance under incongruent conditions pitted against performance in neutral conditions; d' with performance under incongruent conditions pitted against performance in congruent conditions; d' with performance under congruent conditions pitted against performance in neutral conditions; and, only in direct measure [b], d' with performance under congruent and incongruent conditions pitted against performance in neutral conditions. (Note that this d' measure, which corresponds to the one originally devised for the shape detection task by Klotz & Neumann, 1999, was not computed for the rotation detection task, because averaging hit rates across congruent and incongruent conditions in the rotation detection task would have meant averaging across the most divergent stimulus conditions in terms of visual stimulus rotation.)

Average d' values across participants were tested against zero by *t* tests, with an average d' that is not significantly different from zero indicating chance performance in the direct measure—that is, no evidence for an ability to consciously detect the feature in question. Average d' values from the direct-measure task [b] or measure [c]

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that exceeded zero were tested (a) for significant differences to average d' values derived from Task [a] (by within-participant t tests) and (b) for significant correlations with the average d' values derived from Task [a].

Results

Table 1 shows the main results. For the indirect measure, out of all trials, 3.4% in Group A and 3.6% in Group B were excluded from the analyses because response times exceeded 1,000 ms. Repeated measures analyses of variance (ANOVAs) of individual means of correct responses, conducted separately for Groups A and B, with the one within-participant variable of *prime type* (congruent vs. neutral vs. incongruent), led to significant prime type effects: Group A, $F(2, 30) = 43.21$, $p < .01$; Group B, $F(2, 30) = 143.06$, $p < .01$. RT was higher in incongruent (Group A, RT = 468 ms; Group B, RT = 470 ms) than in neutral (Group A, RT = 421 ms; Group B, RT = 428 ms) and congruent (Group A, RT = 404 ms; Group B, RT = 407 ms) conditions, and it was higher in neutral than in congruent conditions, all six ts(15) > 4.52, all six ps < .01 (Bonferroni adjusted). These RT differences were also reflected in significant differences from zero in the d' analyses of the indirect measure (see Table 1). There was also no indication of a speed–accuracy trade-off. ANOVAs of arc-sine transformed error rates with the same variable that was used for the analyses of RTs led also to a significant main effect of prime type: Group A, $F(2, 30) = 19.33$, $p < .01$; Group B, $F(2, 30) = 26.46$, $p < .01$. Error rate was higher under incongruent conditions (Group A, error rate = 9.3%; Group B, error rate = 5.3%) than under neutral (Group A, error rate = 1.3%; Group B, error rate = 1.2%) and congruent conditions (Group A, error rate = 0.9%; Group B, error rate = 1.1%), all four significant ts(15) > 4.20, all four ps < .01.

In line with findings of Klotz and Neumann (1999), the shape detection task (i.e., the direct measure, [b]) indicated chance performance or zero sensitivity for information contained in the masked prime (see Table 1). Moreover, this pattern of chance performance in the shape detection task held true, irrespective of whether d'

Table 1. *Results of Experiment 1*

			d'				
Task	*Group*	*Compared conditions*	*Mean*	*Range*	t	n	p (one-tailed)
a. Masked priming	A	Incongruent vs. congruent[a]	1.16	0.46 to 2.42	9.87	16	<.01
		Neutral vs. congruent	0.35	0.00 to 1.22	5.10	16	<.01
		Incongruent vs. neutral	0.81	0.23 to 1.98	7.57	16	<.01
	B	Incongruent vs. congruent[a]	1.38	0.35 to 2.67	8.53	16	<.01
		Neutral vs. congruent	0.32	−0.08 to 0.81	4.48	16	<.01
		Incongruent vs. neutral	1.06	−0.23 to 1.88	9.31	16	<.01
b. Shape detection	A	Congruent vs. incongruent[a]	−0.03	−0.77 to 0.28	−0.39	16	.35
		Congruent vs. neutral	−0.02	−0.77 to 0.28	−0.31	16	.38
		Incongruent vs. neutral	0.01	−0.40 to 0.21	−0.36	16	.43
		[Cong. + inc. vs. neutral	0.02	−0.21 to 0.58	0.44	16	.33]
c. Rotation detection	B	Incongruent vs. congruent	0.63	−0.20 to 3.80	1.98	16	<.05
		Neutral vs. congruent	0.40	−0.43 to 2.56	1.70	16	.06
		Incongruent vs. neutral[a]	0.23	−0.13 to 1.28	2.37	16	<.05

[a]For the sake of consistency, differences between hit rates from congruent and incongruent conditions are also expressed as d' values, although the convention of signal detection theory does not apply here that one of the judgement classes used for the computation of d' represents an incorrect response. Analyses that were only done for direct measure [b] but not for indirect measure [a] and measure [c] are given in square brackets.

indices were computed by (a) pitting hit rates from congruent plus incongruent conditions against false-alarm rates under neutral conditions (as was done in the original study), (b) pitting hit rates only from congruent conditions against false-alarm rates from neutral conditions, or (c) pitting hit rates only from incongruent conditions against false-alarm rates from neutral conditions. Even the direct comparison between the hit rates from congruent and incongruent conditions did not yield any evidence that hit rates differed as a function of the type of prime–mask sequence employed.

However, in marked contrast to this pattern of results, participants in the rotation detection task were significantly better than chance in detecting rotation (i.e., in measure [c]): Two out of three possible d' measures were significantly higher than zero, and there was at least a tendency toward a significant deviation of d' from zero in the third possible measure, too.

Additional analyses comparing average d's between the two significant measures in Group B—indirect measure [a] and measure [c]—indicated a higher average d' in indirect measure [a] than in measure [c] with d' computed as a difference (a) between hit rates from incongruent conditions and false alarm rates from neutral conditions and (b) between hit rates from incongruent conditions and false-alarm rates from congruent conditions, both ts(15) > 2.30, both ps $< .05$. There was no significant difference between indirect measure [a] and measure [c] in Group B, if d' was computed as the difference between hit rates from congruent conditions and false-alarm rates from neutral conditions, $t < 1.00$. There were no significant correlations between indirect measure [a] and measure [c], with correlation coefficients ranging from $r = .23$ to $r = .28$, all ps $> .30$. See also Figure 2.

Discussion

Experiment 1 replicates the dissociation between an RT priming effect of masked primes (i.e., the indirect measure, [a]) and the shape detection task (i.e., the direct measure, [b]; cf. Klotz & Neumann, 1999). In line with a DPS effect, we found sensitivity for shape information contained in the masked prime in a target-response task, in which primes were suited to activate a response, but in direct measure [b] participants performed on a chance level if the task was to detect trials with a response-relevant target-like shape prime. Moreover, this pattern held, irrespective of

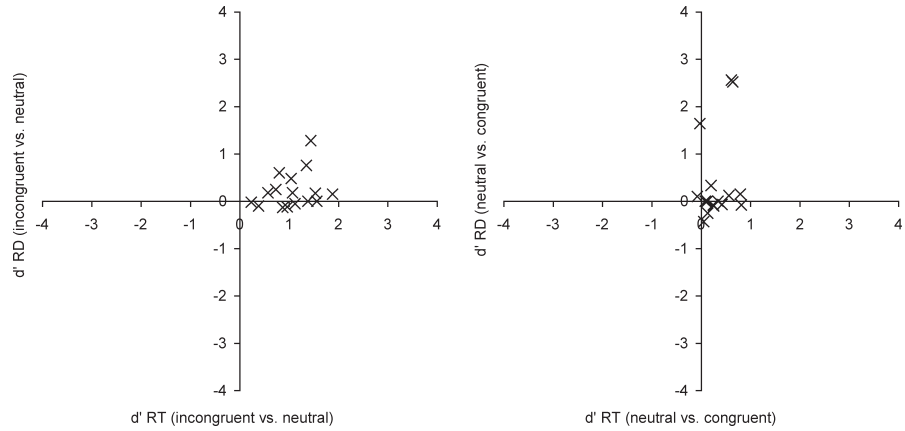

Figure 2. *Data from Group B of Experiment 1. Participants' individual reaction time effects in the target-response task (indirect measure, [a]) on the ordinates—in terms of individual d′ values (d′ RT)—as a function of the participants' performance in the measure, [c], on the abscissas, also in terms of individual d′ values (d′ RD). Left panel: d′ values based on differences between hit rates in incongruent conditions and hit rates in neutral conditions. Right panel: d′ values based on differences between hit rates in neutral conditions and false-alarm rates in congruent conditions. RT = reaction time; RD = rotation detection. For details refer to the Methods and Results sections.*

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whether hit rates were derived from congruent conditions only, incongruent conditions only, or congruent plus incongruent conditions. Therefore, hit rates in the shape detection task were seemingly similarly affected by the masks in congruent and incongruent conditions, an observation also confirmed by a direct comparison between hit rates from congruent and incongruent conditions.

However, more visibility of the masked primes was reflected in a measure lying half-way in between a direct and an indirect measure that required participants to detect visual rotation. In measure [c], participants were significantly better than chance in detecting rotation in incongruent conditions than in both congruent and neutral conditions. Because instructions mapping different judgement classes (rotation: yes vs. no) to different response hands were only given after the target–distractor displays we are also relatively certain that contributions by DPS to the performance in measure [c] were successfully prevented—that is, we believe that the direct measure was indeed an exclusive measure of residual conscious perception. Thus, the rotation detection task was sensitive for information contained in the prime–mask sequence and, by implication, for information contained in the prime, too, under conditions in which shape information per se about the masked prime was no longer available for the report in the direct measure. This finding casts doubts on the classical interpretation that the shape detection task indeed provided an exhaustive measure of residual prime perception in the metacontrast dissociation paradigm.

However, it should be noted that this shortcoming certainly does not preclude the possibility that processing of unconscious input (via DPS) contributes to the RT priming effect. In particular, we found that at least the RT-elongating effect of an incongruent prime in the indirect measure, [a], of Experiment 3's Group B performance was stronger than the accompanying rotation detection capability of the same participants reflected in measure [c]. Moreover, there was no significant correlation between the significant indirect measure [a] and the significant measure [c], as might have been expected if the RT priming effect in measure [a] indeed reflected the participants' ability to consciously perceive rotation and, thus, the primes in measure [c]. Therefore, the masked priming effect in the indirect measure, [a], fulfils two out of three criteria of processing of unconscious input that have been advocated in the past (Naccache & Dehaene, 2001; Reingold & Merikle, 1988, 1990). It only fails on the zero-awareness criterion (cf. Dienes & Scott, 2005; Klotz & Neumann, 1999).

We also did not find any significant evidence for the possibility that participants were uniformly and systematically led astray by the kind of detection task that was being used by Klotz and Neumann (1999). In the Introduction, we argued that the participants' ability to consciously perceive rotation and base their judgement in a shape detection task on rotation perception could have misguided them. In particular, participants might have used perceived rotation for inferring that no target-shaped prime was presented but used the absence of perceived rotation for inferring that a target-shaped prime was presented. If it were true that participants used such a judgement strategy under the shape detection conditions (in the direct-measure task, [b]) we would have expected differences between average d' values based on hits from congruent versus neutral conditions and hits from incongruent versus neutral conditions. Yet, d' values were similar under these different scoring conditions. Of course, it is possible that something more complicated than our hypothetical scenario occurred. For instance, about half of the participants might have used perceived rotation for inferring the presence of a target-shaped prime in the shape detection task, [b], whereas the other half of the participants might have used perceived rotation for inferring the absence of a target-shaped prime in Task [b]. However, if it were true that participants used perceived rotation for consistently inferring either the presence or the absence of a prime in the shape detection task, we would have expected to find maxima or minima of d' under shape detection conditions that matched the maxima or minima of d' found under rotation detection conditions (in the direct measure, [c]), and yet this was clearly also not the

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case (see Table 1). Still, it could be that an even more complex strategy based on perceived rotation accounted for the negative findings in the shape detection task. For instance, individual participants might have oscillated between two strategies, one using rotation for inferring the presence of a target-shaped prime and a second one using rotation for inferring the absence of a target-shaped prime, with occasional trial-by-trial shifting between these two different strategies.

In any case, the important question concerning Experiment 1 is whether residual prime perception—as it was evident in the rotation detection task (measure [c])—could have possibly accounted for performance in indirect measure [a]. At least three general arguments speak against this possibility. First, as already mentioned, the finding that measure [a] is more sensitive than measure [c] and the nonsignificant correlations between direct measure [a] and the hybrid measure [c] argue against this possibility.

Second, previous findings from lateralized readiness potentials (LRPs) indicate that masked shape primes are processed independent of and prior to the targets. The LRP reflects activity in primary motor cortex concerning which response hand (left vs. right) is activated before response execution. In line with a target-independent response activation effect of masked primes preceding the processing of the target, an incongruent masked prime initially activates its motor response in the LRP, before this activity is overridden by a target-induced LRP (Eimer & Schlaghecken, 1998; Leuthold & Kopp, 1998; Vath & Schmidt, 2007). Thus, perception of motion that is only possible after the target seemingly occurs too late to account for the LRP effect of the masked prime.

Finally, an explanation of the indirect-measure effect (RT priming effect) as being due to the conscious perception of rotation leaves us with the task of explaining how perception of rotation could have mimicked the RT effect of congruent and incongruent shape primes on target RTs. Prior research with masked primes indicated that RT effects in indirect measures are conditional on the task relevance of the invisible prime features (cf. Ansorge, 2004; Ansorge, Heumann, & Scharlau, 2002; Kunde, Kiesel, & Hoffmann, 2003; Eckstein & Perrig, 2007). Ansorge and Neumann (2005), for example, demonstrated that if a task-irrelevant masked prime has another colour from that of the relevant target, the RT priming effect in the indirect measure is eliminated. Because motion was not a relevant feature in the RT priming task (measure [a]) of the present Experiment 1, it is unclear how motion should have created an RT priming effect. But of course, it is conceivable that the currently observed effect of rotation was different from the standard masked priming effects in that it was due to conscious perception and that it was independent of motion relevance: It might simply take a longer time to perceive a visually rotating stimulus than it takes to perceive a visually stable (not rotating) stimulus. As a consequence, RT should have increased with the likelihood that a rotating stimulus was perceived—that is, RT should have increased from congruent to neutral and from neutral to incongruent conditions. Experiments 2 and 3 were conducted to rule out this possibility.

EXPERIMENT 2

In Experiment 2, we tested whether rotation perception accounts for the RT effects in indirect measure [a]. To that end, we used the same stimuli and procedures as those in Experiment 1, with the following notable exceptions. In each trial, the visible target was red, and the visible distractor was black (or vice versa; balanced across participants), and participants were instructed to respond to the side of the colour target rather than to the side of the shape target. This makes shape an irrelevant feature. What is more, primes always had the same colour as targets presented at the primes' positions. Therefore, all conditions were colour congruent, providing a high incentive for the participants to follow the instructions (to respond to the colour stimulus) and not to use the redundant shape information for the determination of their responses. Under these conditions, the DPS account of the indirect-measure effect, [a], and the conscious rotation perception explanation outlined

above lead to different predictions. If it is true that masked shape priming effects in indirect measure [a] are conditional on the task relevance of the shape (as predicted by the DPS theory and the explanation of the masked priming effect by Klotz & Neumann, 1999), then the RT priming effect should be eliminated in Experiment 2 (cf. Ansorge & Neumann, 2005). However, if it simply takes longer to perceive a rotating stimulus and that this time to perceive the stimuli accounts for what has been called the RT priming effect, then we expected the same result as that in Experiment 1: RTs should increase from congruent to neutral and from neutral to incongruent conditions.

Method

Participants

A total of 12 volunteers (7 female, 5 male) with a mean age of 28 years participated in Experiment 2.

Apparatus, stimuli, and procedure

These were the same as those in the direct measure, [a], of Experiment 1, except as noted. First, the former shape targets from Experiment 1 were now also discriminated on the basis of their colour. For half of the participants, former shape targets were always red (and distractors were black). For the other half of the participants former shape targets were always black (and distractors were red). Second, primes had always the same colour as the target or distractor stimuli presented at the same position. Third, participants were instructed to respond to the side of the colour target. Half of the participants responded to red targets (and had to ignore black distractors). The other half of the participants responded to black targets (and had to ignore red distractors). Prime shape detection and rotation detection performance were not measured.

Results

For the indirect measure, out of all trials, 3.3% were excluded from the analyses because responses exceeded 1,000 ms. Repeated measures ANOVAs of individual means of correct responses with the one within-participant variable of prime type (congruent vs. neutral vs. incongruent) did not lead to a significant prime type effect, $F < 1.00$. RTs were about the same in congruent (310 ms), neutral (312 ms), and incongruent (312 ms) conditions. By contrast, the same ANOVAs calculated over the arc-sine transformed error rates showed a significant main effect of prime type, $F(1, 11) = 4.21$, $p < .05$. Error rate was higher under incongruent conditions (2.2%) than under congruent conditions (0.9%), $t(11) = 2.92$, $p < .05$, with the error rate of the neutral condition (1.3%) lying in between that of congruent and that of incongruent conditions.

Discussion

The results of Experiment 2 are clear. The change of the targets together with the change of the task instructions eliminated the RT priming effect of shape congruence in an indirect measure [a]. Although there was a shape congruence effect in the error rates, it was reduced in comparison to that in Experiment 1. In conclusion, there is very little indication that the participants are generally slower in shape-incongruent or shape-neutral conditions than in shape-congruent conditions. These results are definitely at variance with the assumption that the degree of perceived rotation per se accounts for the masked priming effect in indirect measure [a]. Instead, the results of Experiment 2 are well in line with the assumption that shape has to be a relevant feature to yield a significant RT priming effect of the masked shape primes in indirect measure [a]. This finding nicely fits the predictions of DPS theory, according to which invisible primes are processed in the extent that the primes' features match the currently searched-for relevant target features (cf. Ansorge & Neumann, 2005; Neumann, 1989, 1990; Scharlau & Ansorge, 2003).

However, participants might have ignored the trailing target and mask altogether in Experiment 2. Participants could have correctly responded on the basis of the primes alone because all trials used colour-congruent conditions. In line with that assumption, responses in Experiment 2 were very fast. Thus, in contrast

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to the results of Experiment 1 and Klotz and Neumann (1999), participants might have responded before their perception of rotation, thereby escaping its harmful influence on target responses under shape-incongruent conditions. Also, we did not measure the participants' ability to perceive rotation in Experiment 2: One could also argue that participants in Experiment 2 could have simply perceived less of the response-delaying visual rotation than did the participants in Experiment 1. As a consequence, we would have observed a shape congruence effect for the rotation perceivers of Experiment 1 but not for the "rotation-blind" participants of Experiment 2. Experiment 3 tested both of these possibilities.

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EXPERIMENT 3

In Experiment 3, we once again tested whether rotation perception accounts for the RT effects of masked shape primes as evident in the indirect measure [a] of Experiment 1. In Experiment 3, like in Experiment 2, we used colour as a response-relevant feature, but instead of using only colour-congruent conditions, we included colour-neutral and colour-incongruent conditions, securing that participants had to attend the targets and masks for giving a correct response. Colour congruence varied orthogonally to shape congruence. Hence, we were able to test whether an indirect-measure effect of the irrelevant prime shapes on RTs resulted as a consequence of rotation detection. This test could be at least conducted in the colour-neutral and colour-incongruent conditions, in which the requirement of a rotation perception before the response decision was met because participants had to await the targets to give the correct responses.

Previous results show that under conditions as in the present experiment, participants do not perceive the prime colour, but that prime colour nonetheless leads to an RT congruence effect in the indirect measure (Breitmeyer et al., 2004; Schmidt, 2000, 2002). Moreover, along the lines of the DPS account, Tapia and Breitmeyer (2006) used three levels of irrelevant prime–target shape congruence (congruent, neutral, and incongruent) and three levels of relevant prime–target colour congruence, and they reported a selective RT congruence effect of the relevant prime–target colour relation. In contrast, the irrelevant prime–target shape relation was successfully ignored and did not have an effect.

Additionally, in the present experiment, we wanted to rule out that the null effect of the masked prime's shapes (i.e., the masked shape priming effect, [a.1] is due to the participants' unawareness of rotation under the shape-incongruent conditions. To that end, we used three direct measures in Experiment 3: [b] shape detection, [c] rotation detection, and [d] colour detection, together with two indirect measures of [a.1] a shape congruence effect and [a.2] a colour congruence effect on RTs and error rates.

Method

Participants

A total of 24 volunteers (16 female, 8 male) with a mean age of 29 years participated in Experiment 3.

Apparatus, stimuli, and procedure

These were the same as those in Experiment 1, except for the following six changes. First, in each trial, one of the clearly visible target display figures was red, and the other one was black: Half of the participants had to respond to the red target and to ignore the black mask, and the other half received the reverse stimulus–response mapping. Second, colours (red or black) and shapes (square or rectangle) of primes and masks varied independently from one another. Thus, in contrast to Experiment 2, it was secured that the participants had to attend to the target colour and that target shape could not be used instead of target colour to correctly respond to the target. Third, there were three types of prime–target colour congruence conditions: congruent conditions, with a black prime and a red prime preceding a black target (or else distractor) and a red distractor (or else target) at their respective positions; incongruent conditions, with positions of the black prime

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and the red prime reversed relative to that of the black target and the red distractor; and neutral conditions, with no target-like coloured prime at all (e.g., with two red primes, if the target was black, one prime at the position of the upcoming target, the other prime at the position of the upcoming distractor). Fifth, shape congruence varied orthogonally to colour congruence. Sixth, an additional direct measure [c], colour detection, was included to test whether participants were able to consciously perceive the prime colours, and an additional indirect measure [a.2], a colour congruence effect on RTs and error rates, was used to check whether prime–target colour congruence had the expected effect—that is, led to more efficient performance under congruent than under neutral and less efficient performance under incongruent than under neutral conditions. Like with the other direct measures, for the direct measure [d] mapping of response hands (left vs. right) to detection judgements (target-coloured prime: present or absent) was balanced across participants.

The two indirect measures were derived from one session, and another three sessions were administered for recording the data for the different direct measures in different blocks. Indirect measures were always taken first, and the order of the different direct-measure task sessions was balanced across participants. Colour- and shape-congruent, colour- and shape-neutral, and colour- and shape-incongruent conditions were equally likely. Also, each particular colour and shape prime and colour and shape target or distractor was equally likely presented to the left or to the right, and each successive pair of prime and target stimuli was equally likely above or below screen centre. For the indirect measure, participants worked through 432 trials in total, 48 repetitions of the combinations of interest that resulted from orthogonally crossing the variables colour congruence (colour congruent; colour neutral; colour incongruent) and shape congruence (shape congruent; shape neutral; shape incongruent). For each of the direct measures, participants completed 720 trials in total—that is, 80 repetitions of the aforementioned combinations. Prior to each session, participants practised the upcoming task.

Results

Tables 2 to 4 show the main results. Out of the 24 participants, a maximum of 2 participants had to be excluded from some of the measures for the following reasons: either not showing up on one of the four sessions (direct measure, [c], of rotation detection), or not understanding task instructions, as evident by an average performance of above 95% similar responses across the different conditions (direct measures, [b], of shape detection, and [c], of rotation detection), or by rendering a zero rate of below median RTs for the computation of a measure (indirect measures, [a.1] of shape congruence and [a.2] of colour congruence).

For the indirect measures, out of all trials, 2.3% were excluded from the analyses because RTs exceeded 1,000 ms. Repeated measures ANOVAs of individual means of correct responses, with the two within-participant variables of *shape congruence* (shape congruent vs. shape neutral vs. shape incongruent) and *colour congruence* (colour congruent vs. colour neutral vs. colour incongruent), led to a significant main effect of colour congruence, $F(2, 46) = 158.01$, $p < .01$, but no effect of shape congruence, $F(2, 46) = 1.06$, $p = .35$, and no interaction between colour congruence and shape congruence, $F < 1.00$. RT was elevated in colour-incongruent (RT = 401 ms) as compared with colour-neutral (RT = 371 ms) and colour-congruent (RT = 334 ms) conditions, and RT was also higher in neutral than in congruent conditions, all three ts$(23) > 8.11$, all three ps $< .01$ (Bonferroni adjusted). These colour congruence effects were also reflected in significant differences from zero in the d' analyses of the indirect measure [a.2]; see Table 2). Moreover, there was no speed–accuracy trade-off: ANOVAs of arc-sine transformed error rates with the same variables confirmed a significant main effect of colour congruence, $F(2, 46) = 30.63$, $p < .01$, with performance being inferior under incongruent (error rate = 5.3%) relative to

Table 2. *Results of the indirect measures of Experiment 3*

			d′				
Task		*Compared conditions*	*Mean*	*Range*	*t*	*n*	*p* (one-tailed)
a.1. Masked shape priming	Colour congruent	s.-incongruent vs. s.-congruent[a]	−0.06	−0.80 to 0.58	−1.00	23	.17
		s.-neutral vs. s.-congruent	−0.06	−0.48 to 0.37	−1.10	23	.16
		s.-incongruent vs. s.-neutral	−0.01	−0.44 to 0.74	−0.11	23	.46
	Colour neutral	s.-incongruent vs. s.-congruent[a]	−0.01	−0.56 to 0.54	−0.15	23	.44
		s.-neutral vs. s.-congruent	0.09	−0.33 to 0.73	1.40	23	.09
		s.-incongruent vs. s.-neutral	−1.00	−0.44 to 0.21	−2.18	23	<.05
	Colour incongruent	s.-incongruent vs. s.-congruent[a]	0.06	−0.65 to 0.91	0.82	23	.21
		s.-neutral vs. s.-congruent	0.04	−0.49 to 0.84	0.64	23	.27
		s.-incongruent vs. s.-neutral	0.02	−1.49 to 0.83	0.17	23	.43
a.2. Masked colour priming	Shape congruent	c.-incongruent vs. c.-congruent[a]	1.19	0.05 to 2.18	10.72	23	<.01
		c.-neutral vs. c.-congruent	0.62	−0.23 to 1.74	5.94	23	<.01
		c.-incongruent vs. c.-neutral	0.57	−0.63 to 1.61	4.83	23	<.01
	Shape neutral	c.-incongruent vs. c.-congruent[a]	1.29	−0.13 to 2.83	9.74	23	<.01
		c.-neutral vs. c.-congruent	0.76	−0.10 to 1.56	8.34	23	<.01
		c.-incongruent vs. c.-neutral	0.53	−0.63 to 1.81	3.95	23	<.01
	Shape incongruent	c.-incongruent vs. c.-congruent[a]	1.31	0.39 to 2.63	10.27	23	<.01
		c.-neutral vs. c.-congruent	0.67	−0.03 to 1.51	7.35	23	<.01
		c.-incongruent vs. c.-neutral	0.64	−0.38 to 2.00	5.22	23	<.01

Note: s. = shape; c. = colour.

[a] For the sake of consistency, differences between hit rates from congruent and incongruent conditions are also expressed as *d′* values, although the convention of signal detection theory does not apply here that one of the judgement classes used for the computation of *d′* represents an incorrect response.

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neutral (error rate = 0.6%) and congruent (error rate = 0.4%) conditions, both significant *t*s(23) > 5.62, both *p*s < .01. In the error ANOVA, neither a significant main effect of shape congruence nor a significant interaction between colour and shape congruence was observed, both *F*s < 1.00.

Corroborating the findings of the present Experiments 1 and 2 (see also Klotz & Neumann, 1999), in six out of nine comparisons, participants did not perform better than at chance level in the shape detection task. Direct measure [b] was not significantly different from zero (see Table 3). Interestingly, though, this time we observed at least one indication that computing *d′*, with hit rates sampled across shape-congruent and shape-incongruent conditions, can decrease the sensitivity of the direct measure: The largest *d′* measure[1] that we observed in the present experiment was computed when congruent and incongruent hit rates were pitted against one another—that is, with a difference between the hit rates in shape-congruent and in shape-incongruent conditions. These differences between the hit rates are hidden, if hit rates are averaged across shape-congruent and shape-incongruent conditions. Note, however, that the finding was restricted to the colour-neutral conditions, thus explaining why a corresponding sensitivity difference between differently computed *d′* measures of shape detection was not observed in the present Experiments 1 and 2. Moreover, as Klotz and Neumann (1999) used colour-congruent conditions, in which there was no indication that

[1] For the sake of consistency, differences between hit rates from congruent and incongruent conditions were also expressed as *d′* values in Table 1, although the convention of signal detection theory does not apply here that one of the judgement classes used for the computation of *d′* represents an incorrect response.

Table 3. *Results of the direct measures [b] and [c] of Experiment 3*

			d′				
Task		*Compared conditions*	*Mean*	*Range*	*t*	*n*	*p* (one-tailed)
b. Shape detection	Colour congruent	s.-congruent vs. s.-incongruent[a]	−0.02	−0.58 to 0.39	−0.32	23	.38
		s.-congruent vs. s.-neutral	0.04	−0.49 to 0.54	0.64	23	.27
		s.-incongruent vs. s.-neutral	0.05	−0.39 to 0.92	0.87	23	.20
	Colour neutral	s.-congruent vs. s.-incongruent[a]	−0.10	−0.58 to 0.26	−2.00	23	<.05
		s.-congruent vs. s.-neutral	−0.06	−0.53 to 0.27	−1.60	23	<.05
		s.-incongruent vs. s.-neutral	0.04	−0.30 to 0.48	0.85	23	.20
	Colour incongruent	s.-congruent vs. s.-incongruent[a]	0.03	−0.25 to 0.29	0.80	23	.22
		s.-congruent vs. s.-neutral	0.002	−0.39 to 0.33	0.05	23	.48
		s.-incongruent vs. s.-neutral	−0.03	−0.44 to 0.48	−0.53	23	.30
c. Rotation detection	Colour congruent	s.-incongruent vs. s.-congruent	0.30	0.05 to 2.18	1.90	22	<.05
		s.-neutral vs. s.-congruent	0.14	−0.23 to 1.74	1.61	22	.06
		s.-incongruent vs. s.-neutral[a]	0.16	−0.63 to 1.61	2.03	22	<.05
	Colour neutral	s.-incongruent vs. s.-congruent	0.41	−0.13 to 2.83	2.52	22	<.05
		s.-neutral vs. s.-congruent	0.19	−0.10 to 1.56	1.83	22	<.05
		s.-incongruent vs. s.-neutral[a]	0.23	−0.63 to 1.81	2.76	22	<.05
	Colour incongruent	s.-incongruent vs. s.-congruent	0.31	0.39 to 2.63	1.88	22	<.05
		s.-neutral vs. s.-congruent	0.17	−0.03 to 1.51	1.71	22	.05
		s.-incongruent vs. s.-neutral[a]	0.14	−0.38 to 2.00	1.51	22	.08

Note: s. = shape.

[a]For the sake of consistency, differences between hit rates from congruent and incongruent conditions are also expressed as *d′* values, although the convention of signal detection theory does not apply here that one of the judgement classes used for the computation of *d′* represents an incorrect response.

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d′ differed across shape-congruent and shape-incongruent conditions, in the present study the manner in which Klotz and Neumann computed *d′* also cannot have been the responsible factor for finding of a chance level performance in their direct measure of shape detection.

The overall absence of any indication that the participants consciously perceived the prime shapes was also confirmed by a more conventional analysis of the rates of yes responses by an ANOVA with the same variables as those that were being used in the analysis of RTs. In this analysis, the main effect of shape congruence, $F < 1.00$, and the Shape Congruence × Colour Congruence interaction, $F(4, 88) = 1.51$, $p = .21$, failed to become significant. This was also true for the main effect of colour congruence, $F(2, 44) = 2.78$, $p = .07$, although we observed a tendency toward significance here, which reflected an increase of the rate of yes responses from colour-congruent and colour-neutral (both rates = 0.56) to colour-incongruent (rate = 0.58) conditions.

Again, in contrast to the null findings in measure [b], participants performed significantly better than chance whilst detecting rotation (i.e., in the direct measure, [c]): Seven out of nine possible *d′* measures were significantly different from zero, and the remaining *d′* indices at least tended toward being significantly different from zero. Also, the three *d′* indices that were expected to yield the strongest differences, because they pitted rotation detection performance under incongruent conditions (with two rotating prime–target sequences per display) against rotation detection performance under congruent conditions (with no rotating prime–target sequence per display) were all significantly different from zero (see Table 3).

Finally, mean performance in the direct measure (d) of colour detection revealed that participants also did not see the prime colours: None

of the nine possible d' indices was significantly different from zero. However, a closer look at Table 4 reveals that the ranges of d' indices based on comparisons of yes responses under (a) colour-congruent against colour-neutral and (b) colour-incongruent against colour-neutral conditions were smaller than the range of d' indices derived by a comparison between colour-congruent and colour-incongruent conditions.

Confirming that the variance of d' increases along with the range of d's, variances differed significantly for different levels of the variable colour congruence, $\chi^2(2, N = 23) = 19.97$, $p < .01$. In the same ANOVA of the rates of yes responses (with the same variables as those that were being used of analysing RTs), however, neither for shape congruence nor for the interaction of shape congruence and colour congruence did variances differ significantly, both ps $> .5$. It should be noted, however, that the ANOVA also confirmed the null findings of the d' analysis, because the main effect of colour congruence, $F(2, 44) = 1.26$, $p = .30$, and the Colour Congruence × Shape Congruence interaction, $F < 1.00$, were not significant. Unexpectedly, however, we found a significant main effect of shape congruence, $F(2, 44) = 4.13$, $p < .05$, with the rate of yes responses under shape-congruent and shape-neutral conditions (both rates = 0.53) being reduced relative to the shape-incongruent conditions (rate = 0.55). This effect probably reflects the participants' use of the visible feature of rotation (see direct measure [c]) instead of the colour feature for solving the task of detecting of the imperceptible target-like colour among the primes.

Discussion

Results of Experiment 3 confirmed that participants saw rotation more frequently under shape-incongruent than under shape-congruent conditions, reflected in the hybrid measure [c] (see also Experiment 1). However, RTs and error rates under shape-congruent and shape-incongruent conditions were about the same in the indirect measure, [a.1], of shape congruence between prime and target (see also Experiment 2). Thus, the lack of a shape congruence effect in indirect measure [a.1] was not due to the participants' inability to perceive rotation under metacontrast conditions with an incongruent prime–target sequence. Instead, it was obviously the task irrelevance of the shapes for the required responses that prevented shape congruence to have an effect in indirect measure [a.1] of Experiment 3 (cf. Tapia & Breitmeyer, 2006).

Table 4. *Results of the direct measure, [d], of Experiment 3*

			d'				
Task		*Compared conditions*	*Mean*	*Range*	t	n	p (one-tailed)
d. Colour detection	Shape congruent	c.-congruent vs. c.-incongruent[a]	−0.10	−1.60 to 0.98	−0.99	23	.17
		c.-congruent vs. c.-neutral	−0.01	−0.38 to 0.57	−0.25	23	.40
		c.-incongruent vs. c.-neutral	0.09	−0.51 to 1.51	0.98	23	.17
	Shape neutral	c.-congruent vs. c.-incongruent[a]	−0.08	−1.55 to 1.28	−0.74	23	.24
		c.-congruent vs. c.-neutral	0.03	−0.40 to 0.71	0.61	23	.28
		c.-incongruent vs. c.-neutral	0.11	−0.57 to 1.46	1.26	23	.11
	Shape incongruent	c.-congruent vs. c.-incongruent[a]	−0.13	−1.78 to 0.81	−1.36	23	.10
		c.-congruent vs. c.-neutral	−0.05	−0.75 to 0.71	−0.83	23	.22
		c.-incongruent vs. c.-neutral	0.09	−0.31 to 1.03	1.32	23	.10

Note: c. = colour.

[a]For the sake of consistency, differences between hit rates from congruent and incongruent conditions are also expressed as d' values, although the convention of signal detection theory does not apply here that one of the judgement classes used for the computation of d' represents an incorrect response.

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As in Experiment 2, participants responded to the position of a prespecified colour target. Under these conditions and in line with previous research, colour congruence between masked prime and visible target had an impact on RTs to the visible targets, reflected in indirect measure [a.2]. This was the case, although the primes' colours were obviously invisible, too, as evident in the direct measure [d] (cf. Schmidt, 2002). Note that this impact of the invisible prime colours cannot have reflected perceived rotation interfering under shape-incongruent conditions (relative to shape-congruent conditions), because colour congruence and shape congruence varied independently from one another. In fact, effects of colour congruence in indirect measure [a.2] were about the same under shape-congruent, shape-neutral, and shape-incongruent-conditions, with no significant elevation of the RTs in the shape-incongruent condition as compared to the shape-neutral and shape-congruent conditions (see Figure 3).

We also observed three unexpected findings. First, under colour-neutral conditions, in direct measure [b], the shape detection task, d' derived from hit rates under shape-congruent relative to shape-incongruent and shape-neutral conditions suggested that participants might have had a residual capacity to detect the shape of the masked prime. Note that this is not certain and that the significance of the finding might well be a chance observation, given that (a) t tests were not corrected for multiple uses of the same means, and (b) one significant test roughly corresponded to the baseline probability of a chance significant observation, given an $\alpha = .05$ and altogether 15 d' indices derived for the shape detection task in the present three experiments.

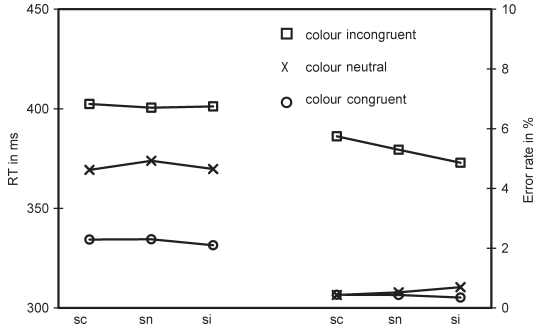

Figure 3. *Mean reaction times (RTs) in ms (on the left) and error rates in percentages (on the right) as a function of colour congruence (colour congruent, colour incongruent, colour neutral) and shape congruence (shape congruent, shape neutral, shape incongruent) in Experiment 3. sc = shape congruent; sn = shape neutral; si = shape incongruent.*

Yet, if the effect is real, the question arises as to what might have caused it in Experiment 3, but prevented it in the preceding experiments. One reason that the effect was only observed in Experiment 3 is that under colour-neutral conditions, the masked prime had a different colour from that of the target at its position. By contrast, no such difference between prime and target colour existed in any of the preceding experiments of the current study and that of Klotz and Neumann (1999), in which only colour-congruent conditions were used. Thus, it is possible that a prime with a colour different from that of the trailing mask is less severely masked than a prime with a colour similar to that of the trailing mask. Note, however, that this explanation is at odds with the colour detection performance in the colour-incongruent conditions of the present experiment and of previous studies: Although in colour-incongruent conditions, colours change at two positions, colour detection performance is usually at a chance level in colour-incongruent conditions (cf. Schmidt, 2002). In conclusion, it is therefore more likely that the colour detection performance in the colour-neutral conditions reflected a chance significant finding.

A second unanticipated finding in Experiment 3 is that in the direct measure [d] of colour detection, the participants' tendency to respond yes (i.e., a prime with target-like colour was present) increased from shape-congruent and shape-neutral to shape-incongruent conditions. At a first glance, the effect seems to indicate that participants must have been able to detect the masked prime shapes. However, in light of the participants' ability to detect rotation but their inability to detect shape, it is more likely that participants used rotation instead of shape or colour

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for the judgements in the colour detection task. One might wonder why rotation was used for the judgements in the colour detection but not in the shape detection task. We do not know for certain, but a speculative answer is that on a phenomenal level motion and colour might have been more akin than motion and shape. Visual flicker, for instance, could be a feature that the participants more frequently perceived under uncertain colour and motion perception conditions than under uncertain shape perception conditions.

Finally, a third unexpected finding was the increased d' range (or the increased d' variance) in the colour detection task, when d' was based on a hit rate difference between colour-congruent and colour-incongruent conditions. In this case, the range or variance of d' was much larger than when hit rate differences were calculated between (a) colour-congruent and colour-neutral and (b) colour-incongruent and colour-neutral conditions (see Table 3). In our view, this kind of d' range effect is diagnostic of the participants' better ability to discriminate between colour-congruent and colour-incongruent conditions than to discriminate between conditions with a target-like coloured prime (in the colour-congruent and colour-incongruent conditions) and conditions without a target-coloured prime (in the colour-neutral condition). However, the fact that d' ranges increased without a concomitant increment of average d' means that the perceived feature that was discriminated was not identified. Otherwise, participants should have accurately and consistently mapped the discriminated feature on the respective judgement alternatives yielding an increased mean d'. In other words, the perceived feature is not identical with the to-be-discriminated prime colour. For the sake of the example, let us again assume that participants saw more flicker in the colour-incongruent than in the colour-congruent conditions. Then, some of the participants could have correctly taken perceived flicker as signalling the presence of a target-like colour prime, whereas other participants could have mistakenly judged the opposite, taking flicker as being diagnostic of the absence of a target-like colour prime. Under such conditions, the d' range becomes largest, if it is computed as a difference between the perceptually most different conditions. It is in this sense that the d' range differences suggested a residual visibility of either masked prime colour or a perceptual correlate of prime colour.

Be that as it may, the residual ability of the participants to perceive that feature (whether the colour change itself or something else) cannot fully account for performance in measure [a.2], the colour-congruence effect: Whereas in an ANOVA of the yes rates in the colour detection task (the direct measure [d]) the perceived feature increased the yes response rate under colour-incongruent relative to colour-congruent and colour-neutral conditions, we observed no significant increase of the yes response rates under colour-neutral relative to the colour-congruent conditions (see also Table 4). By contrast, in the indirect measure [a.2] of colour congruence on RTs, we observed that performance was also significantly facilitated under colour-congruent relative to colour-neutral conditions (besides being significantly halted under colour-incongruent relative to colour-neutral conditions). This facilitative RT effect of the colour-congruent primes in the indirect measure [a.2] was, thus, not accompanied by a corresponding difference in the direct measure, [d], of colour detection performance.

GENERAL DISCUSSION

In the metacontrast dissociation, direct and indirect measures of prime processing have previously been shown to dissociate with what seemed to be an exhaustive direct measure of residual conscious prime perception (cf. Klotz & Neumann, 1999). Klotz and Neumann used geometrical shapes—a diamond and a square—as visible targets and masked primes. They found that presentation of a congruent masked prime before the target (e.g., a masked diamond prime presented at the position of a diamond target) facilitated a response to the target, whereas presentation of an incongruent prime before the target (e.g., a masked diamond prime presented at the position of a square

target) interfered with the response to the target. Importantly these results were found, although in a prime shape detection task participants were not able to discriminate between trials that contained a target-like shape prime and trials without such a target-like shape prime. Klotz and Neumann (1999) eventually used all variants of the prime detection task to render their direct measure of prime perception an exhaustive measure of conscious perception. Yet, they failed to find evidence for the conscious perception of the shape of the masked primes. Therefore, up until today, Klotz and Neumann's study is one of the most convincing demonstrations that unconscious visual inputs can be processed.

Based on theoretical and empirical grounds (e.g., Kolers, 1963), however, we argued that even under the conditions of the metacontrast dissociation, motion perception resulting from prime–mask sequences could have prevailed. In particular, participants might have been able to more reliably perceive rotation under incongruent than under neutral or congruent conditions. These expectations were corroborated by the results of the current Experiments 1 and 3. In Experiments 1 and 3, participants were able to detect rotation more frequently under incongruent than under neutral and congruent conditions, although participants failed in a prime shape detection task. Thus, the use of a relatively insensitive and by far not exhaustive measure task might have been responsible for what appeared to be processing of masked primes being dissociated from conscious perception of the masked primes as reflected in the metacontrast dissociation.

However, on theoretical grounds alone it is not clear that residual capabilities to perceive rotation under incongruent conditions could have been responsible for the RT priming effect in the direct measure. First, rotation detection is a measure lying half-way in between an indirect measure (an indirect effect of the prime, e.g., on target perception) and a direct measure (reflecting perception of the prime itself) because perceiving rotation requires taking into account both prime and target. Therefore, it is not absolutely correct to consider rotation detection performance a measure of prime perception because rotation detection performance similarly rests on processing of the target.

Second, we also used two alternative measures to corroborate the conclusion that (part of) the RT priming effect in indirect measure [a] could have reflected processing of unconscious input. We found that performance in the measure of rotation detection that was significantly different from zero did not significantly correlate with the performance in the indirect measure in Experiment 1, although one would have expected such a correlation if RT priming effects were indeed due to residual rotation perception. In Experiment 1, we also found that the RT priming effect (the indirect measure, [a]) was more sensitive for the information contained in the masked primes than was the measure of rotation detection, [c]. Thus, empirically, we found that even if it were justified to consider the rotation detection task a direct measure, the metacontrast dissociation failed on only one out of three criteria of the processing of unconscious visual input that have been advocated in the past.

Third, again on theoretical grounds, we devised an experimental test for the possibility that conscious rotation perception accounted for the RT priming effect in the indirect measure. We argued that if rotation generally slowed perception and RTs, thus mimicking an assumed effect of the masked shape primes, then changing the task instructions in such a way that processing of the shapes was no longer necessary, masked shape priming effects should still be observed. By contrast, on the basis of the assumptions of the DPS theory, we expected that changing the task relevance of the shape primes should eliminate the masked shape priming effect in the indirect measure (cf. Ansorge et al., 2002; Ansorge & Neumann, 2005; Neumann, 1989, 1990). In Experiments 2 and 3, we changed the targets so that participants were able to select the target on the basis of its colour rather than only on the basis of its shape and found that this eliminated the shape congruence effect in the indirect measure. These results confirmed the predictions of the DPS theory. They also showed that

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perception of rotation per se does not better account for the effects in the masked priming task (i.e., the indirect measure). To note, the colour congruence effect observed in Experiment 3 (see also Breitmeyer et al., 2004; Schmidt, 2002; Schmidt et al., 2006; Tapia & Breitmeyer, 2006; Vath & Schmidt, 2007) cannot be explained by rotation perception. Moreover, at least facilitation of RTs in masked colour-congruent relative to colour-neutral conditions reflected a dissociation—that is, processing of invisible prime colours: Participants could not reliably discriminate between prime colours in colour-congruent versus colour-neutral conditions according to the direct measure, [d], of colour detection.

In conclusion, the development of an exhaustive measure of conscious perception and the demonstration of the processing of unconscious visual input is not a one-step procedure. It requires our continued efforts to come up with ever new variants of probing residual perception in each particular empirical instance. In the present study, this investigation strategy was exemplified with one of the most impressive demonstrations of the capacity to process unconscious visual input, the so-called metacontrast dissociation. The fact that it turned out to be relatively easy to create a new measure for that paradigm that did not dissociate from the indirect measure should remind us that a similar conclusion is probably advised in other paradigms as well. However, we also devised a new test derived from DPS theory that could and should be used to decide whether a particular measure is better conceived of as a direct or an indirect measure.

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