Limited transfer of subliminal response priming to novel stimulus orientations and identities

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Recently, priming effects of unconscious stimuli that were never presented as targets have been taken as evidence for the processing of the stimuli's semantic categories. The present study explored the necessary conditions for a transfer of priming to novel primes. Stimuli were digits and letters which were presented in various viewer-related orientations (upright, horizontal, inverted). The transfer of priming to novel stimulus orientations and identities was remarkably limited: In Experiment 1, in which all conscious targets stood upright, no transfer to unconscious primes in a non-target orientation was found. Experiment 2, in which primes were presented without masks, ruled out the possibility that primes were presented too short to allow congruency effects. In Experiments 3 and 4, in which all targets were presented upside down, priming transferred to upright stimuli with target identities but neither to horizontal stimuli nor to stimuli with novel identities. We suggest that whether a transfer of priming to unpracticed stimuli occurs or not depends on observers' expectations of specific stimulus exemplars.

How do stimuli that people are not aware of gain influence on their behavior? Almost from the first demonstration of the effects of unconscious stimuli, this question has been hotly debated. One such demonstration is the response-congruency effect in subliminal priming experiments: Responding is faster to clearly visible targets if these are preceded by unconscious primes that are assigned to the same response (congruent trials), as compared to trials where primes are assigned to another response (incongruent trials).

In subliminal priming experiments, presentation of a prime leads to measurable neuronal activation in cortical motor areas that are related to the response assigned to the prime (Dehaene et al., 1998; Eimer & Schlaghecken, 1998). The mechanism underlying prime-induced motor activation is, however, unclear. Dehaene et al. concluded that a prime elicits a covert motor response (which facilitates performance in congruent trials and impairs it in incongruent ones) by means of it's semantic properties: "Because this motor parameter was determined by whether the prime was larger or smaller than 5, the prime must have been categorized at the semantic level." (Dehaene et al., 1998, p. 599).

This view has been challenged however. Damian (2001) argued that participants acquire target-response associations during experimental practice trials. When these targets occur as primes some time later, they trigger a covert motor response via a consciously learned and persisting memory trace of stimulus-response episodes without deep semantic processing. This reasoning was corroborated by Abrams and Greenwald (2000) who demonstrated that "robust unconscious semantic priming . . . requires previous classification of visible targets that contain the fragments later serving as primes." (Abrams & Greenwald, 2000, p. 118).

Most challenging for accounts that deny semantic processing of subliminal stimuli are demonstrations of priming effects from subliminal stimuli that were never presented as targets (e.g. Naccache & Dehaene, 2001). Since participants never had to respond to these primes, stimulus-response associations could not have been learned.

Experimentally, priming by novel stimuli has been realized three-fold: Novel primes might (a) have the *same identities* as practiced targets but a *different perceptual format*. For example, Dell'Acqua and Grainger (1999) found priming effects from pictures when targets were the names of the depicted concepts. Steiner (2003), however, failed to find priming from number words when all targets were Arabic numerals (see also Kunde, Kiesel, & Hoffmann, 2003, Experiment 4). Novel primes might (b) have *different identities* than the targets but the *same perceptual format*. Naccache and Dehaene (2001) presented the digits 1, 4, 6, and 9 as targets in a

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numerical judgment task (smaller vs. larger than 5). The digits 2, 3, 7, and 8 led to congruency effects although not being part of the target set. However, when words denoting small or large objects were categorized regarding object size, only those object names activated responses subliminally which had been presented as targets (Damian, 2001). Novel primes might (c) have *different identities and* a *different perceptual format*. For example, Klauer, Eder, Greenwald, and Abrams (2007) found congruency effects of positive and negative adjectives in a valence classification task with smiley faces and grumpy faces as targets. Yet, the number words two, three, seven, and eight did not elicit congruency effects in a numerical quantity judgment task that had to be performed on the digits 1, 4, 6, and 9 (Kunde et al., 2003). Taken together, a transfer of priming to novel unseen stimuli seems to occur under specific conditions but it is far from being a robust phenomenon.

Greenwald, Abrams, Naccache, and Dehaene (2003) reconcile the inconsistent evidence by assuming that primes in principle can activate both long-term semantic memory codes and short-term memory codes established within the experimental context but that ”across all relevant studies, contextual memory effects on masked priming have tended to dominate those based on long-term memory” (Greenwald et al., 2003, p. 245). Kunde et al. (2003) propose a similar account differing from that of Greenwald et al. (2003) mainly with respect to the temporal order of these processes. Kunde et al. (2003) suggest that long-term semantic codes primarily operate prior to task performance, namely during task instructions and initial practice trials, to segment internal representations of potential stimulus events into appropriate and inappropriate response conditions (”action triggers”). Subsequently unconscious primes are processed only up to a level that allows detection of the stimulus' perceptual match or mismatch with an action trigger. As a consequence, priming occurs for all stimuli that are expected regarding both identity and perceptual appearance (see also Kiesel, Kunde, & Hoffmann, in press).

The aim of the current study was to further elaborate on the transfer of subliminal response priming to novel stimuli. We aimed at finding conditions in which priming by novel stimuli emerges robustly. When scanning available evidence, two conditions seem to be especially suitable to demonstrate transfer of priming to novel stimuli: First, novel primes contain fragments of consciously experienced targets (Abrams & Greenwald, 2000; Greenwald et al., 2003). Second, all experimental stimuli are numbers (Naccache & Dehaene, 2001; Kunde et al., 2003). Numbers appear particularly suitable, because semantic access to number meaning is especially fast, and automatic activation of number meanings has been found even in tasks for which number meaning was irrelevant (Brysbaert, 1995; Dehaene & Akhavein, 1995; Dehaene, Bossini, & Giraux, 1993; Fias, Brysbaert, Geypens, & d'Ydewalle, 1996).

Experiment 1 of the present study was designed to test whether robust transfer of priming to novel stimuli can be achieved when both of the above conditions are met. Experimental stimuli were numbers, and novelty was achieved by presenting primes in different orientations than targets. Although this orientation change can be considered a relatively moderate format change when compared to previous format manipulations, the transfer of priming failed. Experiment 2 rules out that the lack of priming by novel stimuli in Experiment 1 was due to short presentation and prime-target SOA. In Experiment 3, target orientation was varied compared to Experiment 1 and 2. Targets were now presented upside down instead of upright. As a consequence, priming by masked stimuli did transfer to a subset of perceptually novel stimuli: Primes in upright presentation induced priming effects whereas horizontal primes again remained ineffective. Experiment 4 was designed to extend the findings of Experiment 3 to identity-defined novelty. Although the transfer of priming to a novel format was replicated, priming did not transfer to novel stimulus identities. Altogether, the apparently complex pattern of transfer suggests that subliminal stimuli exert priming to the extent to which their identity and physical appearance are expected.

Experiment 1

Participants were to classify numerals as smaller or larger than five. All target digits stood upright. Prime numerals had the same identities as the targets but were presented in different orientations (upright, horizontal, inverted). Compared to other format changes used in the literature, this seems to be a rather moderate modification of prime and target appearance (compare e.g. ' ⊣ - 4 ' with ' FOUR - 4 ').

The orientation manipulation establishes conditions under which a transfer of priming appears highly probable: *First*, all stimuli are numbers. *Second*, primes do not only contain fragments of the targets but are physically identical with them (except for orientation). The identification of consciously experienced rotated digits is essentially unaffected by plane rotation (e.g. Corballis, Zbrodoff, Shetzer, & Buffer, 1978; White, 1980). Specifically, Koriat and Norman (1989) demonstrate that the time needed to decide whether a digit is odd or even is independent of its orientation (Koriat & Norman, 1989, Experiment 3)[1]. So if the same identification procedures which are used for conscious stimuli apply to unconscious stimuli as well (Naccache & Dehaene, 2001), an impact of rotated primes is clearly predicted.

Method

Participants. Twelve volunteers (aged 16-32) took part in an individual session of approximately 60 minutes either in fulfillment of course requirements or in exchange for pay. All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

Apparatus and stimuli. An IBM-compatible computer with a 17 inch VGA-Display was used for stimulus presentation and response sampling. Stimulus presentation was syn-

[1] There is some evidence for orientation effects under specific experimental conditions (Jolicoeur & Landau, 1984) which will be considered in Experiment 2.

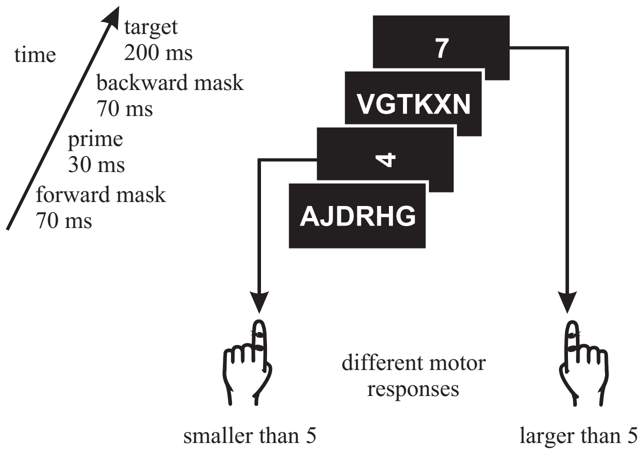

Figure 1. Experiment 1: Sequence of stimuli illustrated with an incongruent trial.

chronized with the vertical retraces of a 100 Hz monitor, resulting in a vertical refresh rate of 10 ms. Responses were executed with the index fingers of both hands and collected with the ’a’ key of the keyboard and the ’6’ key of the number pad.

All stimuli were presented in Arial in white on a black background. A character extended approximately 1 cm in height and 0.8 cm in width. Four Arabic numerals (3, 4, 6 and 7) were used as targets and primes. Targets were always upright (0°). The primes could occur in any of four orientations (0° , ±90°, and 180°).

Each trial had the following structure (see Figure 1): Primes were presented for 30 ms. They were preceded and followed by a random letter mask consisting of six letters with a duration of 70 ms. The target was presented for 200 ms immediately after the post mask. The next trial started 1000 ms after the participant had responded.

Procedure. Half of the participants were asked to press the ’a’ key with the left index finger when the target was smaller than 5 and the ’6’ key on the number pad with the right index finger when the target was larger than 5 as fast and accurately as possible. For the other half of the participants the response mapping was reversed. Incorrect responses were indicated by an error message (the german word for wrong, ”falsch” in red letters) and excluded from reaction time analysis.

Participants completed one practice and seven test blocks, each consisting of 64 different trials (4 primes x 4 orientations x 4 targets). After each block, participants received feedback about their mean reaction time and rate of correct responses, and were allowed to take a short break.

The experiment finished with a detection task to test participants’ awareness of the primes. Participants were fully informed about the sequence of the stimuli in each trial and the precise structure of the primes. Then they completed another two blocks of 64 trials. The only differences to the first part of the experiment were that the task was to decide whether the *prime* was smaller or larger than 5 instead of the target and that no error feedback was provided.

Table 1
Experiment1: Mean response times (RT in milliseconds), error rates (PE in percent, in brackets) and response-priming effects (RPE). RPE which differ significantly from 0 are marked with asterisks.

prime orientation	*congruent RT (PE)*	*incongruent RT (PE)*	*RPE RT*	*RPE PE*
0°	453 (3.7)	479 (4.5)	26*	0.8
90°	464 (3.3)	463 (4.1)	-1	0.8
180°	465 (3.7)	467 (3.4)	2	-0.3

Results

Response congruency. Table 1 displays mean response times and error rates in Experiment 1. Responses with RTs 2.5 standard deviations above and below the participant’s average were discarded (1.8% of the data). We also excluded trials with physically identical primes and targets (same number and orientation) from analysis because such primes may facilitate perceptual encoding of the targets and would therefore artificially inflate differences between the effects of upright primes and primes in other orientations (Koechlin, Naccache, Block, & Dehaene, 1999).

Mean RTs for correct responses were submitted to an analysis of variance (ANOVA) with repeated measures on the variables *congruency* (congruent or incongruent), and *prime orientation* (0°, 90°[2], or 180°). Two effects turned out to be significant: the main effect of congruency (10 ms, $F(1,11) = 18.3,\ p < .001$) and the interaction of congruency and prime orientation ($F(2,22) = 20.3,\ p < .001$). As can be seen in Table 1, the overall congruency effect is based solely upon the upright primes.

The above ANOVA was also conducted for percent error as the dependent variable, to confirm that the results do not have to be interpreted in terms of a speed-accuracy trade-off. Neither of the factors nor their interactions reached significance (all p-values > .30). Thus there is no indication of a speed-accuracy trade-off.

Prime awareness. The commonly accepted way to prove the absence of prime awareness is to show that participants are not able to distinguish the primes with respect to the task (e.g. to classify them as smaller or larger than 5), indicated by a d’ of 0 in a signal detection task (cf. Erdelyi, 2004).

In our experiment overall sensitivity d’ for the primes[3]

[2] Throughout the analyzes we do not distinguish primes in 90° clockwise and counterclockwise, since rotation effects depend on the magnitude of disorientation but not on it’s direction (e.g. Koriat & Norman, 1989). If prime orientation of +90° and -90° are considered separately there is no priming effect for either orientation.

[3] $d' = z_{hit|<5} - z_{false\ alarm|>5}$, correction for 0% hit and 100% false alarm according to Hautus (1995).

was 0.02 and did not differ significantly from 0 ($F(1,11) = 0.077,\ p = .787$). To rule out that upright primes were detected more easily, we calculated d's for each prime orientation separately and submitted them to a one way ANOVA with repeated measures on the factor *prime orientation* (0°, 90°, 180°). The analysis revealed no differences between the three orientations ($F(2,22) = 0.209,\ p = .813$).

We additionally conducted χ^2-tests for each subject separately to see whether response (left vs. right) and prime magnitude (smaller vs. larger than 5) were statistically independent on the individual level. All 12 p-values were grater than .20 in these tests, indicating that none of the subjects were able to categorize primes correctly above chance level.

To test whether the priming effect is related to prime visibility, a regression analysis as proposed by Draine and Greenwald (1998; see also Greenwald, Klinger, & Schuh, 1995; Greenwald, Draine, & Abrams, 1995) was computed. We regressed the individual congruency effects ($RT_{incongruent}$ - $RT_{congruent}$) on the individual d' values. The linear regression analysis revealed no significant correlation between d' and congruency effects ($r = .381,\ t(11) = 1.30,\ p = .222$). However, the intercept of the regression was larger than zero (intercept $= 5.31,\ t(11) = 3.93,\ p < .01$), indicating that a significant priming effect is associated with d' of zero.

Discussion

A transfer of priming to novel stimuli was not observed. This is remarkable because we had aimed at establishing ideal conditions for such a transfer by using identical numbers as primes and targets and inducing novelty by a rather moderate format change. The lack of transfer is noteworthy because the primes contained all perceptual fragments of the targets. This qualifies the idea that such a transfer occurs for primes that contain target fragments (Abrams & Greenwald, 2000). It seems that the transfer must bear on strictly viewer-related representations of fragments that become entirely inefficient after rotation.

One explanation for the absence of a priming transfer to a novel format might be that the format change was not as moderate as assumed. One might argue that disoriented stimuli first have to be mentally rotated or otherwise recoded into an upright representation in order to extract the necessary magnitude information. This mental rotation or recollection of upright representations might take more time than is available within a presentation time of 30 ms and a prime-target SOA of 100 ms. Also, Jolicoeur and Landau (1984) observed orientation effects with short presentation times in a numeric identification task. Therefore, it seems momentous to test whether rotated stimuli are processed at all under the present task conditions. This was done in Experiment 2.

Experiment 2

If it had been shortness of SOA and prime-presentation that bar rotated primes from evoking congruency effects in Experiment 1, then congruency effects should be absent even when primes were not masked. We therefore reran Experiment 1 without masks. Priming from unmasked horizontal and inverted stimuli would rule out the objection that their processing takes too long to lead to response-congruency effects with presentation times as short as those used in Experiment 1.

Table 2
Experiment 2: Mean response times (RT in milliseconds), error rates (PE in percent, in brackets) and response-priming effects (RPE). RPE which differ significantly from 0 are marked with asterisks.

prime orientation	*congruent RT (PE)*	*incongruent RT (PE)*	*RPE RT*	*(PE)*
0°	455 (2.6)	507 (7.4)	53*	(4.8*)
90°	450 (2.1)	506 (6.1)	56*	(4.0*)
180°	450 (2.3)	507 (6.1)	57*	(3.8*)

Method

Participants. Twelve volunteers (aged 20 - 36) that had not taken part in Experiment 1 took part in an individual session of approximately 60 minutes either in fulfillment of course requirements or in exchange for pay. All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

Apparatus, stimuli and procedure. Apparatus, stimuli and procedure were the same as in Experiment 1 with one critical exception: there were no longer masks.

Results

Response congruency. Table 2 displays mean response times and error rates in Experiment 2. Responses with RTs 2.5 standard deviations above and below the participant's average were discarded (1.9% of the data). For the same reasons as in Experiment 1, we excluded trials with physically identical primes and targets (same number and orientation) from analysis.

Mean RTs from correct responses were submitted to an analysis of variance (ANOVA) with repeated measures on the variables *congruency* (congruent or incongruent), and *prime orientation* (0°, 90°, or 180°). Only the main effect of congruency was significant (53 ms, $F(1,11) = 146,\ p < .001$). As can be seen in Table 2, all orientations contributed to the overall congruency effect. Most importantly, there were no differences between congruency effects of primes in different orientations (interaction of congruency x prime orientation: $F(2,20)$[4] $= 2.37,\ p = .125$).

The above ANOVA was also conducted for percent error as the dependent variable. The main effect of congruency was significant (4.2 %, $F(1,11) = 12.8,\ p < .010$). Participants made more errors in incongruent than in congruent

[4] Greenhouse-Geisser correction of degrees of freedom was applied here and in all subsequent analyzes where sphericity was violated.

trials (6.6 % and 2.3 % respectively). Neither the factor orientation nore the interaction of congruency and orientation were significant.

Prime awareness. In this experiment overall sensitivity d' for the primes was 2.6 and differed significantly from 0 ($F(1,11) = 76.3,\ p < .001$). The one way ANOVA with repeated measures on the factor *prime orientation* (0°, 90°, 180°) revealed no differences between sensitivities for numerals in different orientations ($F(2,22) = 0.918,\ p = .414$).

χ^2-tests for each subject separately confirmed that responses (left vs. right) depended upon the magnitude of the primes (smaller vs. larger than 5). χ^2_1-values lay between 34 and 120 resulting in p-values smaller than .001.

Discussion

Experiment 2 was conducted to examine whether the absence of congruency effects from rotated subliminal primes in Experiment 1 was due to shortness of prime presentation and prime-target SOA (30 ms and 100 ms respectively). The results are clear cut: Effects of *unmasked* primes with the same duration and SOA are independent of orientation. Thus, it seems that it is lack of awareness of rotated primes rather than shortness of presentation which disabled priming from these stimuli. Yet, one may still argue that short presentation duration together with masking prevented rotated primes from being mentally rotated into an upright orientation in Experiment 1. Therefore, we found that it would be most appropriate to demonstrate that even masked inverted primes can produce congruency effects provided they are expected. This was done in Experiment 3.

Experiment 3

Participants in Experiment 3 consciously experienced upside down oriented targets while all other experimental conditions remained the same as in Experiment 1. We now expected inverted primes to produce congruency effects as well. First of all this would rule out the possibility that inverted primes cannot cause congruency effects for some principled reason. Second, this manipulation might help to discriminate between two competing accounts of masked priming. If priming was due to acquired links between responses and actually practiced targets (Abrams & Greenwald, 2000), only inverted primes should evoke response-congruency effects because only for them stimulus-response associations can be established. The action-trigger hypothesis by Kunde et al. (2003) on the other hand could be reconciled with two prime orientations being effective: Since participants are very likely to expect upright numerals when instructed to classify digits into smaller or larger than 5, they eventually activate internal representations of upright numerals as action triggers prior to task performance. Internal representations of inverted numerals would be activated when initial practice trials reveal that such stimuli do occur. Thus, the action-trigger account could explain priming effects from inverted *and* upright primes whereas priming should not transfer to horizontally presented primes.

Table 3
Experiment 3: Mean response times (RT in ms), error rates (PE in %, in brackets), and response-priming effects (RPE). RPE which differ significantly from 0 are marked with asterisks.

prime orientation	*congruent RT (PE)*	*incongruent RT (PE)*	*RPE RT*	*RPE PE*
0°	477 (2.4)	485 (4.0)	8*	1.6
90°	477 (3.4)	477 (3.3)	0	-0.1
180°	473 (2.9)	483 (3.9)	10*	1.0

Method

Participants. Twelve volunteers (aged 19-30), who had not participated in Experiment 1 or 2 took part in an individual session of approximately 60 minutes either in fulfillment of course requirements or in exchange for pay. All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

Apparatus, stimuli and procedure. Apparatus, stimuli and procedure were exactly the same as in Experiment 1 with the exception that all targets were now presented upside down (180°).

Results

Response congruency. Table 3 displays mean response times and error rates in Experiment 3. Responses with RTs 2.5 standard deviations above and below the participant's average were discarded (1.4% of the data) as well as data from trials with physically identical primes and targets. Mean RTs for correct responses were then submitted to an analysis of variance (ANOVA) with the variables *congruency* (congruent or incongruent) and *prime orientation* (0°, 90°, or 180°). The same effects as in Experiment 1 turned out to be significant: the main effect of congruency (6 ms, $F(1,11) = 7.77,\ p < .05$) and the interaction of congruency and prime orientation ($F(2,22) = 3.77,\ p < .05$). T-tests revealed that the difference between response times in incongruent and congruent trials was significant for the upside-down oriented primes (10 ms, $t(11) = 2.96,\ p < .01$) as well as the upright primes (8 ms, $t(11) = 2.42,\ p < .05$). Although the magnitude of the congruency effect is larger for the inverted than for the upright primes, this difference is not statistically significant. Horizontal primes did not induce significant congruency effects.

One could argue that the effect of the inverted primes could actually be an effect of an upright oriented prime, namely if these effects were due to prime 6 only, because an upside down oriented 6 is identical with an upright 9. Likewise, the effects of the upright primes could arise from a seemingly upside down oriented prime, since an upright 6 is identical with an inversed 9. We therefore reran the ANOVA under exclusion of the data from trials where prime

6 had been presented in 0° or 180°. The overall data pattern did not change (main effect of congruency: 7 ms, $F(1,11) = 14.03,\ p < .010$; interaction of congruency and prime orientation: $F(2,22) = 3.10,\ p < .07$). Paired T-tests confirmed that the effect of the inverted primes had not changed significantly. The effect of the upright primes was even significantly increased when prime 6 was excluded from the analysis (8 ms with and 12 ms without prime 6; $t(11) = 3.6,\ p < .01$), whereas one would expect the opposite if the effect of the upright primes had been due to prime 6 only.

The same 2 x 3 ANOVA with percent error as dependent variable revealed no significant results.

Prime awareness. Overall sensitivity d' for the primes was 0.08 and did not differ significantly from 0 ($F(1,11) = 2.25,\ p = .162$). As in Experiment 1 we calculated d' for each prime orientation separately and conducted a one way ANOVA with the factor *prime orientation*. The analysis revealed no differences between the three orientations ($F(2,22) = 0.878,\ p = .430$). χ^2-tests confirmed that for each individual participant response (left vs. right) and prime magnitude (smaller vs. larger than 5) were statistically independent (χ^2_1 values between 0.03 and 1.2, p-values between .830 and .273).

A linear regression analysis revealed no significant correlation between d' and congruency effects ($r = -.133,\ t(11) = -0.425,\ p = .680$). The intercept of the regression was larger than zero (intercept = 4.31, $t(11) = 2.29,\ p < .05$), indicating that a significant priming effect is associated with d' of zero.

Discussion

Experiment 3 showed that inverted primes cause congruency effects provided participants have experienced such stimuli in the experimental context. Moreover the experiment helps to pinpoint which of two different explanations for the absence of priming from rotated stimuli in Experiment 1 is more appropriate, learned 'stimulus-response links' (Abrams & Greenwald, 2000) or prespecified 'action-triggers' (Kunde et al., 2003). Table 4 illustrates which account predicts congruency effects for the different prime orientations (for the sake of completeness predictions of the 'deep semantic analysis' account are added). The results of Experiment 3 are in line with the action-trigger account of subliminal priming. When all targets are presented upside down, priming transfers to the novel but probably expected upright orientation.

However, there is an explanation for the result pattern of Experiment 3 which preserves the idea that semantic codes are accessed unconsciously. This explanation considers the strength of connections between physical and semantic stimulus representations. Upright Arabic numerals are frequent. Indeed their frequency is even higher than that of highly frequent number words (Dehaene & Mehler, 1992). In contrast, rotated numerals are rare in every-day life. So connections between upright numerals and their meaning are well trained and therefore probably much stronger than that between rotated numerals and meaning, resulting in immediate automatic activation of number meaning in case of upright but not in case of horizontal or upside down primes. Yet, there is one result that suggests that the strength of connections between physical and semantic representations does not account for our result pattern: The effects of the upright primes vanished in the course of Experiment 3 (see Figure 2). If number meaning of upright numerals was accessed automat-

Table 4
Predicted effective prime orientations in Exp. 1 and 3 according to three different accounts of subliminal priming.

Exp.	*target orientation*	*prime orientation 0°*	*90°*	*180°*
i) learned stimulus-response links[a]				
Exp. 1	0°	+	-	-
Exp. 3	180°	-	-	+
ii) prespecified action triggers[b]				
Exp. 1	0°	+	-	-
Exp. 3	180°	+	-	+
iii) deep semantic analysis[c]				
Exp. 1	0°	+	+	+
Exp. 3	180°	+	+	+

+ effective prime orientation; - ineffective prime orientation
[a]Abrams and Greenwald (2000); [b]Kunde et al. (2003); [c]e.g. Dehaene et al. (1998)

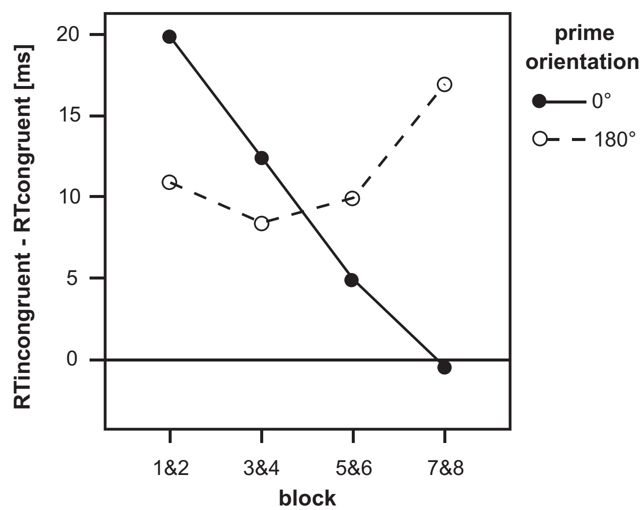

Figure 2. Time courses of the congruency effects in Experiment 3. In contrast to the effect of inverted primes, that of upright primes vanishes in the course of the experiment. (The effects are summarized over 2 blocks a time, because per block each single prime was presented only 2 times in congruent and 2 times in incongruent trials.)

ically (Dehaene & Akhavein, 1995; Greenwald et al., 2003), then the resulting priming effect should be stable throughout the experiment.

The disappearance of priming effects from upright primes suggests an alternative explanation, namely the adjustment of observers' expectations. It seems not too far fetched to assume that participants who are instructed to categorize numerals into smaller or larger than 5 initially await neither horizontal nor inverted digits but upright ones. As the experiment proceeds, observers learn that no (visible) upright digits occur. Together with the decreasing expectancy for upright digits, their impact on performance decreases. A gradual rather than abrupt reduction of priming from upright stimuli might result from the fact that it is not that easy to get rid of an action trigger once it has been set up. This idea is supported by the observation that primes belonging to a certain task set continue to produce priming, even though this task has become irrelevant (Kiesel, et al., in press). In sum, results in Experiments 1 and 3 can be accounted for easily when assuming that only those primes are effective that are most probably expected.

Another explanation might be that presentation of inverted targets in Experiment 3 obliged the recollection of canonical upright representations to classify targets. These recollected upright representations subsequently might serve as action triggers that enable priming from upright primes as well. In Experiment 1, by contrast, subjects might not have been obliged to recode upright targets into an inverted form while classifying targets. First of all, this "obligatory upright recoding" account is not too different from the action-trigger account explained in the introduction. It also assumes that primes can bias behavior only if a corresponding stimulus representation is activated. The main difference seems to be that the obligatory upright recoding account attributes the activation of such trigger representations to *actual* task requirements (classification of inverted targets) whereas we attribute it to *expected* or supposed task requirements. What is more, the obligatory upright recoding account is not easily reconciled with the results of Experiment 2: Since exclusively upright targets where presented, no recoding was necessary to classify targets. Yet, primes in all orientations caused effects and they did so to an almost identical extent. In our view, this renders recoding of inverted stimuli into upright representations in the present task unlikely. Rather it makes sense to assume that participants create other than upright stimulus codes when they consciously experience other than upright stimuli.

Experiment 4

In Experiment 3, priming transferred – at least temporarily – to stimuli in a novel orientation. Experiment 4 was designed to test whether this transfer extends to primes with novel identities.

The number of digits which can be tilted without remaining physically identical or turning into another digit is limited (e.g. 8 in 0° and 180° are identical, 6 in 0° is identical with 9 in 180° and vice versa). Thus number stimuli do not allow us to create conditions with orientation-defined and identity-defined novelty simultaneously. In the present experiment, we therefore switched to letter stimuli. Using letters instead of digits in an orientation manipulation seems unproblematic since – as with single digits – identification times for consciously experienced single letters are unaffected by plane rotation (White, 1980; Koriat & Norman, 1989, Experiment 2; Corballis et al., 1978).

Participants had to decide whether the target letter was a consonant or a vowel. All targets were presented upside down. Primes again were presented in three different orientations (upright, horizontal, inverted) but could additionally have either target or non-target identity. We expected priming by inverted letters and possibly by upright ones. The crucial question was whether a transfer to novel letter *identities* occurred as well.

Method

Participants. Twenty four volunteers (aged 16-32), that had not taken part in one of the former experiments, took part in an individual session of approximately 60 minutes either in fulfillment of course requirements or in exchange for pay. All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

Apparatus and stimuli. The same apparatus as in the first two experiments was used.

Stimuli were eight letters in lower case (a, e, i, u, g, k, r, w). They were presented in Arial in white on a black background, except for the letter u, which was presented in Century Gothic, because an inverted u in Arial looks like n. Targets were the letters a, i, r, and w that were always presented upside down (180°). All eight letters were used as primes. Thus we had two types of primes, 'target primes' (a, i, r, w) and 'non-target primes' (e, u, g, k). Each prime occurred in four orientations (0°, ±90°, and 180°). Masks were composed of five randomly selected special characters (§, $, %, &, #). The structure of the trials was the same as in Experiment 1 and 3.

Procedure. Half of the participants were asked to press the 'a' key with the left index finger when the target was a vowel and the '6' key on the number pad with the right index finger when the target was a consonant as fast and accurately as possible. For the other half of the participants the response mapping was reversed. Incorrect responses were indicated by an error message ("falsch", red letters) and excluded from reaction time analysis.

Participants completed one practice and seven test blocks, each consisting of 128 different trials (8 primes x 4 orientations x 4 targets). After each block, participants received feedback about their mean reaction time and rate of correct responses, and were allowed to take a short rest.

The experiment finished with a detection task. Participants were fully informed about the sequence of the stimuli in each trial and the precise structure of the primes. Participants then completed another two blocks of 128 trials. For

Table 5
Experiment 4: Mean response times (RT in ms), error rates (PE in %, in brackets), and response-priming effects (RPE in ms). RPE which differ significantly from 0 are marked with asterisks.

prime orientation	*congruent RT (PE)*	*incongruent RT (PE)*	*RPE RT*	*RPE PE*
primes with target identity				
0°	489 (5.2)	501 (4.3)	12*	-0.9
90°	500 (4.7)	499 (4.4)	-1	-0.3
180°	494 (5.5)	508 (6.9)	14*	1.4
primes with non-target identity				
0°	499 (4.8)	499 (5.9)	0	1.1
90°	496 (4.7)	497 (4.7)	1	0.0
180°	497 (5.8)	500 (6.4)	3	0.6

the detection task, participants were to decide whether the *prime* was a vowel or a consonant. No error feedback was provided.

Results

Response congruency. Table 5 displays mean response times and error rates in Experiment 4. Responses with RTs 2.5 standard deviations above and below the participant's average were discarded (1.6% of the data) as well as RTs from trials with identical targets and primes (same letter and orientation). Mean RTs from correct responses were then submitted to an analysis of variance (ANOVA) with repeated measures on the within-subject variables *congruency*, *prime identity* and *prime orientation*. Three effects turned out to be significant: The main effect of congruency (5 ms, $F(1,23) = 10.8,\ p < .01$), the interaction of prime orientation and congruency ($F(2,42) = 5.02,\ p < .05$), and the triple interaction of prime orientation, prime identity, and congruency ($F(2,40) = 3.92,\ p < .05$). T-tests revealed that the difference between response times in incongruent and congruent trials was significant only for upright and inverted primes with target identity (0°-target primes: 12 ms, $t(23) = 3.58,\ p < .001$; 180°-target primes: 14 ms, $t(23) = 4.16,\ p < .001$). Primes with non-target identity and primes with target identity in horizontal orientation remained ineffective.

The same ANOVA on percent error revealed no significant results.

Prime awareness. Overall sensitivity d' for the primes[5] was 0.04 and did not differ significantly from 0 ($F(1,23) = 0.385,\ p = .541$). We also calculated d' for each prime orientation and prime identity (target prime vs. non-target prime) separately and submitted them to a 3 x 2 ANOVA with the factors *prime orientation* and *prime identity*. Neither of the factors nor their interaction had a significant influence on sensitivity (all p-values $> .20$). Individual χ^2-tests confirmed that response and prime class (vowel vs. consonant) were statistically independent for 22 participants (p-values $> .20$). The test was significant for one participant ($\chi^2_1 = 4.46,\ p < .10$). However, the overall data pattern of the congruency effects did not change when we excluded this participant from analysis. Moreover, the linear regression analysis revealed no significant correlation between d' and congruency effects ($r = .249,\ t(23) = 1.21,\ p = .241$). The intercept of the regression was larger than zero (intercept $= 3.15,\ t(23) = 2.21,\ p < .05$), indicating that significant priming is associated with d' of zero.

Discussion

In the present experiment, we explored whether the transfer of priming to upright stimuli found in Experiment 3 extends to upright stimuli with *novel identities*. This was not the case: *Target* primes in the unseen upright orientation led to congruency effects, but *non-target* primes with the same orientation did not. Beyond this, the results of Experiment 4 replicate those of Experiment 3 in that upright and inverted (target) primes elicited congruency effects whereas horizontal ones were ineffective.

Why does priming transfer to upright target primes but not to upright non-target primes? In case of numerals, several studies consistently report priming for stimuli with non-target identities (Greenwald et al., 2003; Kunde et al., 2003; Naccache & Dehaene, 2001) whereas these effects repeatedly failed to occur for other stimulus categories (letters: Jacobs, Grainger, & Ferrand, 1995, Experiment 1; words: Abrams & Greenwald, 2000, and Damian, 2001). For an explanation of these contradictory results both the number of potential and the number of presented targets seem to be important (Kiesel, Kunde, Pohl, & Hoffmann, 2006). We refer to this issue in the General Discussion.

Contrary to our results, Reynvoet, Gevers, and Caessens (2005) found priming by letters with novel identities when they used hash marks as masks, which prevent prime visibility less effectively than the present masks (Kunde, Kiesel, & Hoffmann, 2005). Kouider and Dupoux (2004) demonstrate that *partial* awareness alone can produce effects that mimic semantic priming. Reynvoet et al. (2005) did not test prime visibility with those participants who's priming data were analyzed, so we can only speculate that prime visibility is the key to explaining the contradiction.

General discussion

Response-congruency effects of subliminal primes have been attributed to either learned stimulus-response associations that become activated when the respective stimulus is presented subliminally, or to unconscious access to the primes' semantic features. Particularly diagnostic for semantic access is a transfer of subliminal priming to novel prime stimuli that have not been used as targets before, because stimulus-response associations cannot be acquired for such

[5] $d' = z_{hit|vowel} - z_{false\ alarm|consonant}$

stimuli. Prime novelty can relate to either the prime's perceptual appearance, it's identity, or to both. In the present study, perceptual novelty was induced by using unpracticed viewer-related stimulus orientations. Identity novelty was induced by using unpracticed letters from the alphabet.

We found some transfer to primes that appeared in a novel stimulus orientation (Exp. 3 and 4). According to the transfer logic, this suggests a "deep" level of analysis that abstracts to some extent from the physical appearance of the presented stimuli. Yet, this transfer was remarkably limited. It occurred only for a specific, namely upright, stimulus orientation whereas no transfer was observed for upside down or horizontally presented primes. Moreover, there was no transfer of priming to novel stimulus identities. These restrictions appear more in line with a relatively "superficial" prime analysis that bears on specific perceptual representations.

Altogether it seems that neither a semantic nor a stimulus-response link model can be easily reconciled with the present results. On the one hand, a semantic account would have to assume that the normally automatic access to semantic memory for digits and letters is completely switched off by a 90° rotation. In light of the evidence for orientation-independent congruency effects of conscious primes (Experiment 2), it seems unlikely that the priming effects of unconscious objects are mediated by the same processes that mediate conscious identification. On the other hand, a stimulus-response link model would have to assume that such links are created for unpracticed stimuli to account for the transfer of priming to upright primes observed in Experiments 3 and 4.

We recently suggested that apparently inconsistent data patterns like these might be explained by considering how participants prepare for the task. Specifically, our suggestion was that participants, while elaborating task instructions or practicing the task, activate internal representations of potential stimuli as "action triggers" (Kunde et al., 2003; Kiesel et al., in press). Although the classification of potential stimuli into action triggers initially might base on semantic criteria (such as magnitude in numerical tasks), a perceptual match between prime and action trigger eventually suffices to subliminally trigger the corresponding response. Importantly, the set of stimuli that is pre-classified to trigger a response is not necessarily restricted to the actual response set, but might well extent to other stimuli that can reasonably be expected in the experimental context. In a nutshell, it depends on the observer's expectation whether or not a stimulus activates a response. If stimuli of certain identity and perceptual appearance are expected, they bias responding even unconsciously, if they are unexpected they do not.

In our view, this idea can explain the pattern of results we have obtained here. When asked to categorize digits or letters, it seems natural to expect that upright digits and letters would be encountered and, consequently, there was a transfer to upright stimuli that actually never occurred as targets in the experiment.

From the perspective of such a model, the important question is: Which factors shape expectancies? We assume that it is the structure of the consciously seen targets that shapes expectancies. One feature of the target set that seems important to explain why some studies found a transfer to novel stimulus identities (e.g. Grainger & Frenck-Mestre, 1998; Dell'Acqua & Grainger, 1999; Klauer et al., 2007; Quinn & Kinoshita, in press) whereas others did not (e.g. Damian, 2001; Abrams & Greenwald, 2000; the present Experiment 4) is the number of practiced targets. Despite several methodological differences, the former studies share one characteristic: Participants consciously experienced numerous category members as targets (84 targets in Dell'Acqua & Grainger, 1999; 60 targets in Grainger & Frenck-Mestre, 1998; 24-70 targets in Klauer et al., 2007; 180 targets in Quinn & Kinoshita, in press) whereas the number of targets was more restricted in cases that failed to observe transfer of priming. For example, Damian (2001) presented only 12 targets and in the present experiments the target set was even restricted to 4 different exemplars.

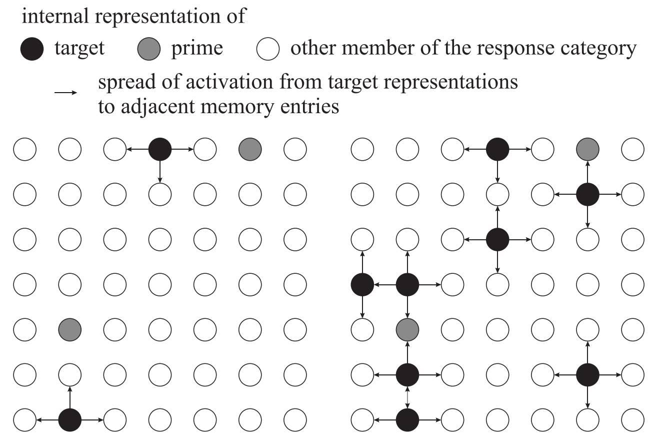

Figure 3. Influence of target-set size on the effectiveness of novel primes. When only 2 out of 49 possible targets are presented, novel primes remain ineffective (left panel). The same novel primes may be able to activate responses when 8 randomly selected targets are presented (right panel).

Although the exact number of targets necessary to obtain transfer of priming is not easily determined and probably depends on other experimental factors, there is independent evidence that target-set size matters. In a study by Kiesel et al. (2006) one group of participants consciously experienced four targets, whereas another group experienced forty targets (names of small vs. big objects). As expected, priming of novel stimuli occurred in the second group only. In light of this study, the ineffectiveness of non-target primes in Experiment 4 could be due to the fact that we presented only four out of twenty six possible letters as targets.

But how does the practiced target set determine whether or not an unpracticed object serves as a trigger event for unconscious response activation? We conjecture that this might happen either in a bottom-up or a top-down manner (cf. Figure 3 for an illustration). The activation of internal representations of consciously practiced response-category members conceivably spreads bottom-up to semantically related representations (Collins & Loftus, 1975). Consequently, stimuli that match these adjacent entries may subsequently activate the response assigned to this category although they were never experienced as targets themselves (Bodner & Masson, 2003). Importantly, the more targets are presented, the more adjacent memory nodes are activated and the higher the probability that a novel prime matches such a node (compare the left and right panels in Figure 3). Note that this probability does also increase with decreasing size of the response categories (cf. Forster, 2004; compare also Van den Bussche & Reynvoet, 2007, and Abrams, in press). Alternatively, it seems possible that memory nodes of category members can become pre-activated in a top-down manner on the basis of instructions and initial practice trials. For example, after having classified the names ”Tim”, ”Mike”, and ”Rick” as male first names it seems reasonable to intentionally prepare for the name ”Steve” as well (Klauer et al., 2007). Such an intentional preparation makes sense when it becomes clear that a broad variety of different objects of a category will occur, whereas it seems superfluous when only two members of each response category occur, as it was the case in the present Experiment 4.

Although we believe that an explanation along these lines has the power to cover a large body of evidence, we do not claim that it covers all existing evidence. For example, expectations might explain the transfer of priming to novel first names in the study by Klauer et al. (2007) as described above, but it does not explain why this transfer depended on prime presentation duration in that study.

Existing studies on subliminal priming (including the present) manipulated observers expectations indirectly by varying features of the consciously experienced targets, such as number of targets (Kiesel et al., 2006), numerical distance between target numerals on the mental number line (Kunde et al., 2003, Experiments 1 and 2), or target format (Steiner, 2003; Kunde et al., 2003, Experiment 4). These studies suggest that novel stimuli have to be expected in order to influence behavior unconsciously (see also Ansorge & Neumann, 2005). Thus, further progress in our understanding of the impact of unconscious material on behavior might come from more direct manipulations of observers' expectations by means of instructions.

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