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Priming of semantic classifications by novel subliminal prime words ☆

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Abstract

Four experiments demonstrate category congruency priming by subliminal prime words that were never seen as targets in a valence-classification task (Experiments 1, 2, and 4) and a gender-classification task (Experiment 3). In Experiment 1, overlap in terms of word fragments of one or more letters between primes and targets of different valences was larger than between primes and targets of the same valence. In Experiments 2 and 3, the sets of prime words and target words were completely disjoint in terms of used letters. In Experiment 4, pictures served as targets. The observed subliminal priming effects for novel primes cannot be driven by partial analysis of primes at the word-fragment level; they suggest instead that primes were processed semantically as whole words contingent upon prime duration.

Keywords: Subliminal; Masked priming; Congruency effects

1. Introduction

To what extent are subliminal stimuli processed semantically? One line of research addressing this question has employed binary categorization tasks, in which visible target stimuli are preceded by masked primes and are to be classified in one of two semantically opposite categories (Greenwald, Klinger, & Schuh, 1995). The primes are either in the same category as targets (congruent) or not (incongruent). A so-called category congruency effect is said to occur if participants respond faster or more accurately (or both) on congruent than on incongruent trials.

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For example, when words are to be classified as positive or negative, target words (e.g., sunshine) are often evaluated faster and more accurately when they are preceded by evaluatively congruent prime words (e.g., priest) than by evaluatively incongruent prime words (e.g., hate; Klauer & Musch, 2003). Category congruency priming of this kind differs from so-called semantic priming (Neely, 1991) in that both congruent and incongruent prime-target pairs are categorically related: Congruent primes and targets share the same category membership (e.g., the category of positive words), incongruent primes and targets are members in semantically opposite categories (e.g., the target is a member of the set of positive words, whereas the prime is a member of the set of negative words). As pointed out by Lambert et al. (2003), a more appropriate structural analogy than the semantic-priming paradigm is Jacoby's (1991) process-dissociation paradigm. For congruent prime-target pairs, responding on the basis of the target as well as responding on the basis of the prime lead to the correct answer. In the language of the process-dissociation method, responding in a controlled way to the target word leads to the same response as responding in the absence of control to the task-irrelevant prime word. For incongruent prime-target pairs, responding in a controlled way to the target and responding to the task-irrelevant prime in the absence of control lead to contradictory responses. Unintentional influences of the prime word are reflected in differences in performance for targets in congruent relative to incongruent pairings.

In this line of research, evidence for reproducible subliminal priming has accumulated. For example, Draine and Greenwald (1998), using a valence-classification task, found replicable category congruency effects for masked prime words selected from the same set as the target words. One way to explain the observed subliminal category congruency effects is to assume that primes are processed semantically. For example, Dehaene et al. (1998) argued that participants unconsciously apply the task set for target processing to the prime words. Congruent prime words thereby acquire the power to evoke the same response as target words, leading to facilitation, whereas incongruent prime words bias the opposite response, leading to interference.

Subsequent results suggested alternative explanations of these findings. Abrams and Greenwald (2000) as well as Damian (2001) found that primes were only effective if they had repeatedly been responded to as visible targets. In other words, there was little priming by new stimuli that had not appeared as targets in the classification task before. Abrams and Greenwald (2000) demonstrated that even fragments consisting of a few letters of prior targets sufficed to elicit category congruency effects; it was not necessary to present the entire word as prime. In a similar vein, Kouider and Dupoux (2004) showed that pseudowords formed by transposing the letters of previous targets can engender similar category congruency effects as the targets themselves when used as primes. Finally, Greenwald and Abrams (2002) found that even single consonants (repeated in a letter string, e.g., LLLLL) from prior targets (tulip) can have this effect. The explanations that were proposed for these findings differ in several respects, as explained next, but they agree that masked primes are not processed as deeply as targets, typically only at the level of word fragments of one or more letters, undermining the hope to demonstrate semantic processing of subliminal primes by means of category congruency priming.

For example, according to an account by *evolving automaticity*, as words are repeatedly classified, an association between the word and the appropriate response (Damian, 2001) or between the word and a more abstract response-related representation such as its response category (Abrams, Klinger, & Greenwald, 2002) is formed, curtailing the need for semantic processing of the word. The associated response-related representation is also activated, although perhaps only weakly, when a target later appears as prime. This biases the response to the current target, accounting for category congruency priming. Note that the account by evolving automaticity must postulate that associations are also formed between word *fragments* and response-related representations to be able to explain the above-reviewed findings.

Another explanation assumes that targets' mental representations are strongly activated in the course of repeated classifications. In this highly activated state, a representation including semantic information about the target's category membership can already be triggered by partial visual information such as by a masked fragment of the whole word. The triggered semantic information then interacts with the category information that is gathered from the current target in an evidence-accumulation response-selection process (Abrams & Greenwald, 2000; Broadbent & Gathercole, 1990), leading to category congruency effects in the absence of a proper semantic analysis of prime words.

In a related account, Kouider and Dupoux (2004) postulated that target identity is sometimes reconstructed from letters or fragments of a word. In their view, masked priming effects are actually effects of reconstructed, fully conscious primes.

Finally, according to the *action-trigger* approach by Kunde, Kiesel, and Hoffmann (2003), participants intentionally specify action triggers in elaborating the task instructions and as a consequence of practice in the task. These action triggers are templates against which target stimuli are matched perceptually. In the case of a match, the response belonging to the matching action trigger is released. Primes have the power to bias responses if they match one of the action triggers perceptually.

All of these accounts require only relatively low-level perceptual analysis of primes to explain category congruency priming. Novel primes should therefore be ineffective as primes if and when they do not share the critical visual features (letters, word fragments) that, as the case may be, are directly associated with response codes, trigger preactivated semantic representations, are used to reconstruct an intact word, or match action triggers. Recently, Naccache and Dehaene (2001), Reynvoet, Caessens, and Brysbaert (2004) Greenwald, Abrams, Naccache, and Dehaene (2003) did however report category congruency effects for novel primes in a number-classification task. For example, Naccache and Dehaene's (2001) participants practised quantity classifications (smaller or larger than five) with just four target numbers: 1, 4, 6, and 9. Nevertheless, unpractised numbers, 2, 3, 7, and 8 engendered significant category congruency effects in masked priming.

Can category congruency priming by novel primes be explained in terms of only partial analyses of primes? According to the above, it needs to be claimed that the critical visual features driving the effects for old primes are shared by novel primes; a claim that is difficult to refute unless it is specified a priori what features precisely can be used (Broadbent, 1987). The account by Kunde et al. (2003) involves a semantic element that allows for even more flexibility: action triggers can include templates for stimuli that were never shown. For example, if participants know that they will be shown one-digit numbers and that their task is to discriminate numbers smaller than five from those larger than five, they are likely to set up triggers that perceptually match all numbers from 1 to 4 for one response and all numbers from 6 to 9 for the other response even before any number stimuli are shown. Since action triggers are responsible for category congruency effects, this means that priming by novel primes is expected as soon as the task context makes it likely that action triggers for such primes are formed. Note that semantic analysis of subliminal primes needs not be assumed.

Nevertheless, as acknowledged by Kunde et al. (2003), this latter argument cannot explain category congruency effects for novel primes from task categories with many perceptually dissimilar members such as the set of all positive (or negative) words or the set of all small (or large) objects. And indeed, Abrams and Greenwald (2000; see also Greenwald and Abrams, 2002), using valence classifications, and Damian (2001), using size discriminations, obtained little evidence for category congruency effects by novel prime words drawn from such potentially large stimulus pools.

The question addressed by the present research is whether there are category congruency effects engendered by masked novel *word* primes. As just reviewed and further elaborated in the General Discussion, the question is theoretically important. There are three previous failed attempts to find the effect. Two of these were reported by Damian (2001; Experiments 2 and 3), the third by Abrams and Greenwald (2000, Exp. 3). All three experiments had relatively small test power; there were 16 participants in each of Damian's experiments and 12 participants in the group that saw novel prime words in Abrams and Greenwald's experiment. The probability of detecting a priming effect of medium effect size ($d = d_3\sqrt{2} = 0.50$; Cohen, 1988, Chapter 2.3) at the 5% level of significance with 16 (12) participants is however only 25% (21%), and for priming effects of smaller size, it is of course even smaller. Thus, the evidence against the existence of category congruency priming by masked novel prime words is not very compelling to date.

Related studies using number stimuli and quantity-classification tasks have produced mixed results. As already mentioned, a number of studies found category congruency priming by masked novel number stimuli (Greenwald et al., 2003; Naccache & Dehaene, 2001; Reynvoet et al., 2004) although such findings were criticized by Kunde et al. (2003) on the grounds that action triggers might be formed for the number stimuli as a consequence of elaborating the task instructions, explaining priming without semantic analysis of masked novel primes. Three experiments by Kunde et al. (2003; Experiments 2, 3, and 4) aimed at making it unlikely that action-trigger templates would be formed for novel number stimuli. In their Experiment 2, category congruency priming was absent for novel primes, but with 12 participants it was unlikely that a small category congruency effect would have been detected according to the above power analysis. In their Experiment 3, a reversed category congruency effect was obtained for novel primes that was however attributed to a non-semantic confounding in visual features between primes and targets. Finally, in their Experiment 4 ($n = 24$), primes were either digits or number words; notation format was varied between participants. Category congruency effects emerged for novel primes given notation matches (i.e., when both prime and target were digits, or both were number words), but was absent for novel and previously classified primes given a notation mismatch between prime and target. However, as recently shown by Van Opstal, Reynvoet, and Verguts (2005) when a slightly different mask was used, category congruency priming appeared even for primes and targets that differ in notation independently of prime novelty (but see Kunde, Kiesel, & Hoffmann, 2005). Finally, Reynvoet, Gevers, and Caessens (2005) recently reported small priming effects by novel number and letter primes in three experiments that they argued could not be explained by alternative explanations of the kind just reviewed and that were instead attributed to semantic processing of novel prime numbers and letters.

Whereas the studies using number and letter stimuli bear only indirectly on the question of the present paper, a number of findings suggest more directly that there might be a small amount of category congruency priming by masked novel prime words. Dehaene et al. (2004) using behavioral and neuroimaging techniques recently reported evidence for subliminal activation of visual word-form information above the letter and word-fragment level, although it remained an open question in this research whether the activated representations contain semantic information. Naccache et al. (2005) furthermore showed that subliminal presentation of novel emotional words that were to be classified as threatening or non-threatening modulated the activity of the amygdala at a long latency, larger than 800 ms, providing evidence for semantic access to emotional valence of these words, in three epileptic patients. Forster, Mohan, and Hector (2003) and Forster (2004; Experiment 4) found category congruency effects by masked novel prime words in an animal-categorization task in two experiments that did not however include a test of prime visibility. A recent study by Greenwald and Abrams (2002), based on first names and a gender-classification task, reported category congruency priming by novel subliminal prime words, but no systematic effort was made to control for confoundings between primes and targets at the level of word fragments of one or more letters. Moreover, we recently proposed a way to disentangle a semantic component from a response-related one in category congruency priming (Klauer, Musch, & Eder, in press). The semantic component of the observed masked category congruency effects was smaller than the response-related one, but unlike the response-related component, it was independent of the amount of practice that primes had previously received as targets. This led us to assume that a residual *semantic* congruency effect might give rise to masked category congruency priming even by novel word primes.

Three of the present four experiments use the valence-classification task, rendering it unlikely that action triggers (Kunde et al., 2003) can be set up a priori to encompass arbitrary novel primes from the large and diverse task categories of positive and negative words. Nevertheless, it is difficult and perhaps impossible to rule out conclusively that relatively low-level perceptual features of the particular used primes and targets are confounded with their category memberships. The difficulty arises from the fact that the class of potentially relevant features is very large. Most of the above approaches have however suggested that word fragments consisting of one or more letters are the critical features. In the first three experiments, we therefore control for confoundings at the letter and word-fragment level. This means that we can rule out alternative explanations of possible category congruency effects in terms of partial analysis of prime words at the word-fragment level. In Experiment 3, the effects of prime novelty and prime duration are additionally explored. In a fourth experiment, we try to rule out orthographical overlap of any kind or level between primes and targets by using pictures rather than words as targets.

2. Experiments 1 and 2

In Experiment 1, primes and targets were selected so that overlap in terms of word fragments of one or more letters was small overall and larger for incongruent pairings (i.e., between positive primes and negative targets, and between negative primes and positive targets) than for congruent pairings (i.e., between positive primes and positive targets, and between negative primes and negative targets). According to accounts based on word fragments as critical prime features, this should lead to a reversal of priming effects, if category congruency priming is at all observed (e.g., Abrams & Greenwald, 2000; Kouider & Dupoux, 2004; Kunde et al., 2003, Exp. 3). In Experiment 2, primes and targets were selected using different letters altogether (see also, Greenwald & Abrams, 2002) so that primes and targets did not share any letters or word fragments.

2.1. Method

2.1.1. Participants

Participants were 66 University-of-Bonn students (33 in Experiment 1, 33 in Experiment 2) with different majors. They received Euro 6 for participating.

2.1.2. Stimuli for Experiment 1

Primes and targets stemmed from a set of 70 strongly polarized positive adjectives and a set of 70 strongly polarized negative adjectives used in previous masked priming studies (e.g., Klauer, Mierke, & Musch, 2003). All words had between three and nine letters. Each set was split into 35 words used as primes and 35 words used as targets by means of a heuristic computer-programmed algorithm designed to minimize overlap in word fragments between congruent primes and targets. Each occurrence of a prime-word fragment in a target word added to the overlap count. In the resulting sets of primes and targets, the overlap in word fragments of three or more letters was 10 between positive primes and targets, 15 between negative primes and targets, 45 between positive primes and negative targets, and 26 between negative primes and positive targets. When word fragments comprising two letters were also included, these numbers were, in order, 272, 308, 350, and 322; when individual letters were included, 3701, 3628, 3789, and 3707. Thus, there was more overlap between primes and targets of different valence than between primes and targets of the same valence. The word sets are shown in Appendix A.

2.1.3. Stimuli for Experiment 2

In Experiment 2, two word pools were drawn from large lexical databases (most words stemmed from the Celex database; Baayen, Piepenbrock, & Gulikers, 1995). First, words with less than three and more than fifteen letters were excluded. The first pool contained all remaining words that used only the letters a, ö, u, ü, b, c, f, h, j, n, q, s, t, y, z, or ß ($N = 285$), the second word pool was based on the letters ä, e, i, o, d, g, k, l, m, p, r, v, w, and x ($N = 557$). Three judges then selected the 35 most positive and the 35 most negative words from each word pool, resulting in two word sets of 70 words each (35 positive, 35 negative) without any overlap in letters. Each word set was then used in a speeded valence-classification task administered to 27 participants (per word set, totalling 54 participants). On the basis of these pilot data the 24 words most consistently classified as positive and the 24 words most consistently classified as negative were selected from each word set. The final word sets thus comprised 48 words (24 positive, 24 negative) and were disjoint in terms of letters. These word sets consist of adjectives and substantives that are also shown in Appendix A.

2.1.4. List Construction

Participants worked through blocks of 48 prime-target pairs that realized a balanced prime valence (positive versus negative) times target valence (positive versus negative) design. In Experiment 2, word set was counterbalanced between participants so that for half of the participants ($N = 17$), words from Set 1 were used as targets and words from Set 2 as primes and vice versa for the remaining participants ($N = 16$).

2.1.5. Procedure

Participants underwent two separate phases: a priming phase and a test of prime visibility. For the priming trials, they were to decide whether target words were positive or negative. For the test of prime visibility, participants were asked to decide whether the masked prime words were positive or negative. Assignment of positive and negative words to the response keys was counterbalanced so that 16 or 17 participants in each experiment responded to positive (negative) words with a keypress initiated by their dominant (non-dominant) hand, and the remaining 17 or 16 responded to positive (negative) words with their non-dominant (dominant) hand.

Participants were seated at a distance of 50 cm from a 43 cm VGA color monitor with 85 Hz refresh rate. Stimulus presentation and measurement of response latencies were controlled by the Inquisit software package that implements video synchronization and millisecond accuracy (De Clercq, Crombez, Roeyers, & Buysse, 2003).

2.1.5.1. Priming Phase. The response window technique proposed by Greenwald, Draine, and Abrams (1996) was used. The technique pushes participants toward responding within a narrow time frame after the presentation of the target. As Greenwald et al. (1996; Draine and Greenwald, 1998) pointed out, it has the major benefit of controlling for speed-accuracy tradeoff problems by reducing variance in the response latencies, thereby avoiding the dilution of the priming effect amongst response latency and accuracy. This typically leads to a large increase in the effect size of priming effects. The dependent variable with this procedure is based on the percentages of correct and false responses rather than on response latencies although we also present response latency analyses.

The sequence of events on priming trials was as follows (see Fig. 1): blank screen for 500 ms, forward mask for 294 ms, prime for 82 ms, backward mask for 12 ms, then target. Masks were letter strings composed of 13 randomly sampled consonants. Masks, primes, and targets were presented in black on a light gray background centered on the middle of the screen in lowercase letters in a bold 12 pt font. Primes were extended to a length of 13 letters by adding random consonants to the left and to the right. For example, the prime word "fair" thereby became "gkvtfairsmltr." This somewhat unusual presentation procedure was intended to depress prime visibility over and above the effects of forward and backward masks (see, e.g., Klauer et al., 2003).

For the response window procedure, the target lasted 333 ms and was followed immediately by an exclamation mark, which stayed on screen for 133 ms and defined the response window interval (see Fig. 1). Participants were instructed to respond while the exclamation mark was on the screen. If participants responded during the window interval, the exclamation mark immediately turned red and persisted for 300 ms. If the exclamation mark disappeared without turning red, participants knew that they were too slow; if the exclamation mark did not appear at all, participants knew they were too fast.

Participants worked through four practice blocks and ten experimental blocks. During practice, the word "FEHLER" (ERROR) appeared immediately after a wrong response. This error feedback appeared in the middle of the screen for 200 ms. Furthermore, strings of 13 random consonants replaced prime words during practice. The first practice block did not include the response window, and participants were instructed to respond as fast and accurately as possible. End-of-block feedback reported both mean latency and percent correct responses for the just completed block. The second practice block introduced the response window. From then on, end-of-block feedback additionally reported percent of trials in which a response occurred during the response window for the just completed block. For the ten experimental blocks, trialwise error feedback was discontinued.

2.1.5.2. Test of prime visibility. For the test of prime visibility, participants also worked through blocks of 48 prime-target pairs constructed exactly like the experimental blocks and presented with the same presentation

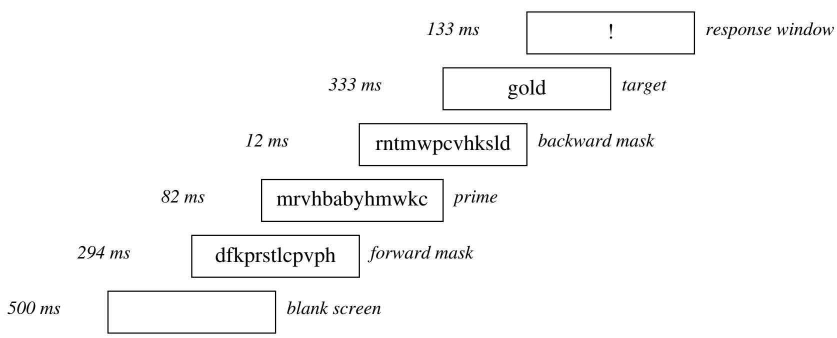

Fig. 1. Sequence and duration of events on priming trials using the response-window procedure in Experiments 1 and 2.

parameters as the experimental trials, including the presentation of targets and the response window stimulus (exclamation mark). There were, however, two initial practice blocks with modified presentation. During practice, correct responses to the prime word's valence were followed by the word "RICHTIG" (CORRECT) in the middle of the screen appearing for 200 ms. For the first practice block, the forward and backward masks were furthermore replaced by blanks, and prime words were presented in red without random consonants to the left and right. This made prime words relatively easy to perceive. The second practice blocks added the forward and backward masks, but primes remained red.

For the following five data-collection blocks, primes were presented as in the priming trials, and trialwise feedback discontinued. Participants received end-of-block feedback about the percentage of prime words correctly classified. There was no time pressure for the direct test. In particular, participants were no longer required to respond while the exclamation mark was visible.

2.1.6. Signal detection measures

Category congruency effects and prime visibility were assessed by means of signals detection d' values (Greenwald et al., 1996). For this purpose, trials with positive primes were considered signal trials and trials with negative primes noise trials. The response "positive" to a signal trial was considered a hit, the response "positive" to a noise trial was considered a false alarm.

2.2. Results

The chosen significance level was $\alpha = .05$ throughout this paper. Exact p values are reported for the test statistics for reasons explained by Greenwald et al. (1996). For the analyses of the priming data, responses with latencies smaller than 100 ms or larger than 1000 ms were excluded thereby leaving out 3.6 and 3.5% of the data in Experiment 1 and 2, respectively. Accuracy data and response latencies for correct responses are shown in Table 1. The category congruency effects were $d' = 0.12$ ($SD = 0.10$) in Experiment 1 and $d' = 0.06$ ($SD = .12$) in Experiment 2. Both effects were significantly different from zero ($t(32) = 6.33$, $p = 10^{-7}$, and $t(32) = 2.95$, $p = .006$, respectively). The factor word set (Set 1 versus Set 2) of Experiment 2 had no effect ($F < 1$).

The d' values for prime visibility were $d' = 0.06$ ($SD = .22$) and $d' = 0.06$ ($SD = .21$) in Experiment 1 and 2, respectively. Both were not significantly different from zero ($t(32) = 1.51$, $p = .14$ and $t(32) = 1.62$, $p = .12$, respectively). The factor word set (Experiment 2) had no effect on prime visibility ($F < 1$).

These findings were confirmed by regression analyses in which category congruency effects were regressed on prime visibility (Greenwald et al., 1995). In these analyses, a significant intercept means that there are category congruency effects in the absence of prime visibility. The regression analysis has the advantage that it

Table 1
Accuracy (in percent) and response latencies (ms) for correct responses

	Incongruent		Congruent	
	M	*SD*	*M*	*SD*
Experiment 1				
Accuracy	73	13	77	13
Latency	493	80	490	80
Experiment 2, Targets from set 1				
Accuracy	73	13	75	12
Latency	489	73	484	72
Experiment 2, Targets from set 2				
Accuracy	69	11	71	12
Latency	450	68	451	64
Experiment 4				
Accuracy	77	8	78	7
Latency	386	38	388	40

does not rely on accepting the null hypothesis of zero prime visibility in testing for category congruency effects in the absence of prime visibility. The intercepts in Experiment 1 and 2 were 0.12 ($SE = 0.02$) and 0.06 ($SE = 0.02$), respectively, both of them significantly different from zero ($t(31) = 6.11$, $p = 10^{-6}$, and $t(31) = 2.68$, $p = .01$, respectively). The category congruency effects were not a function of prime visibility: the regression slopes amounted to −0.03 ($SE = 0.09$) and 0.04 ($SE = 0.10$) in Experiment 1 and 2, respectively (in both cases: $-1 < t < 1$). Moreover, neither the quadratic nor the cubic trend of prime visibility approached significance (in all cases: $|t| < 1$) when these were additionally entered in the regression equation, so that there was no evidence for a departure from linearity in the regression function. The same pattern of results (i.e., a significant intercept and non-significant slope) emerged in the improved regression analyses proposed by Klauer, Draine, and Greenwald (1998) to accommodate measurement error in the prime visibility regression predictor.

Two additional control analyses were run to consolidate these findings, an analysis by items and an analysis of latencies for correct responses. First, an analysis by items with primes as units was performed to assess whether the category congruency effect generalizes over the different prime words or is focussed on a few unusual primes (Clark, 1973). For this purpose, the category congruency effect was computed for each prime word as the difference in the percentage of correct responses between prime-target pairs in which that prime word was paired with congruent targets and prime-target pairs in which it was paired with incongruent targets. In both experiments, the effects were found to generalize over primes ($M = 4.31\%$, $SD = 9.51\%$, $t(69) = 3.79$, $p = .0003$ and $M = 2.35\%$, $SD = 7.77\%$, $t(95) = 2.97$, $p = .004$ in Experiments 1 and 2, respectively).[1] Second, category congruency effects in terms of correct-response latencies (see Table 1) were computed to evaluate the possibility of a speed-accuracy trade-off being responsible for the category congruency effect in the accuracy domain. Note however that such a trade-off, if it occurred, would not compromise the implication that prime valence must have been processed at some level. In terms of correct response latency, the category congruency effects were 3.19 ms ($SD = 11.13$ ms) and 1.97 ms ($SD = 8.30$ ms) in Experiments 1 and 2, respectively, and they were not significant ($t(32) = 1.65$, $p = .11$, and $t(32) = 1.36$, $p = .18$, respectively).

Greenwald et al. (2003) and Abrams (2005) demonstrated that the size of category congruency priming is typically elevated, relative to its overall mean, when examined in a subset of trials selected from the fastest third of the overall distribution of latencies. These analyses were conducted by sorting responses by latency, then examining the category congruency effects for about 50 subsets of responses that were grouped by speed, ranging from the lowest percentiles of the distribution to the highest percentiles. Fig. 2 shows the resulting latency operating characteristic (LOC) functions for Experiments 1 and 2. As is characteristic of the LOC, maximum priming is seen at small latencies and magnitude of priming drops below zero for larger latencies.[2]

[1] To evaluate further the possibility that the category congruency effects were caused by a few primes that were overall more visible than the other primes, two regression analyses were performed relating category congruency effects and prime visibility with primes as unit of analysis. For the first such analysis, the dependent variable was the category congruency effect in percent correct and predictors were (1) prime valence and (2) performance (percent correct) in the visibility test. Prime valence was included to account for effects of possible response bias favoring one of the responses 'positive' or 'negative'; prime valence was coded as -1 = negative and $+1$ = positive, and performance in the visibility test was computed relative to the guessing baseline of 50%. For a second analysis, positive and negative primes were ordered from most visible to least visible on the basis of performance (percent correct) in the visibility test. Pairs of one positive and one negative prime each were then formed such that the first pair contained the most visible positive prime along with the most visible negative prime, followed by a pair with the next most visible positive and negative prime, and so forth. Signal detection d' values were then computed to assess the category congruency effect and prime visibility for each such pair as described in the body of the paper, and d' values for category congruency effects were regressed on d' values for prime visibility over pairs. Both analyses revealed significant positive intercepts and non-significant slopes of prime visibility. The significant positive intercept means that possible differences between primes in prime visibility were not responsible for the observed category congruency effects. In addition, the non-significant slope indicates that the category congruency effects were not a function of prime visibility. The same pattern of results and significances was obtained for the item analyses reported in the other experiments in this paper.

[2] LOC analyses were also conducted for the other experiments reported in this paper, and in each case, the LOC curves showed these characteristics.

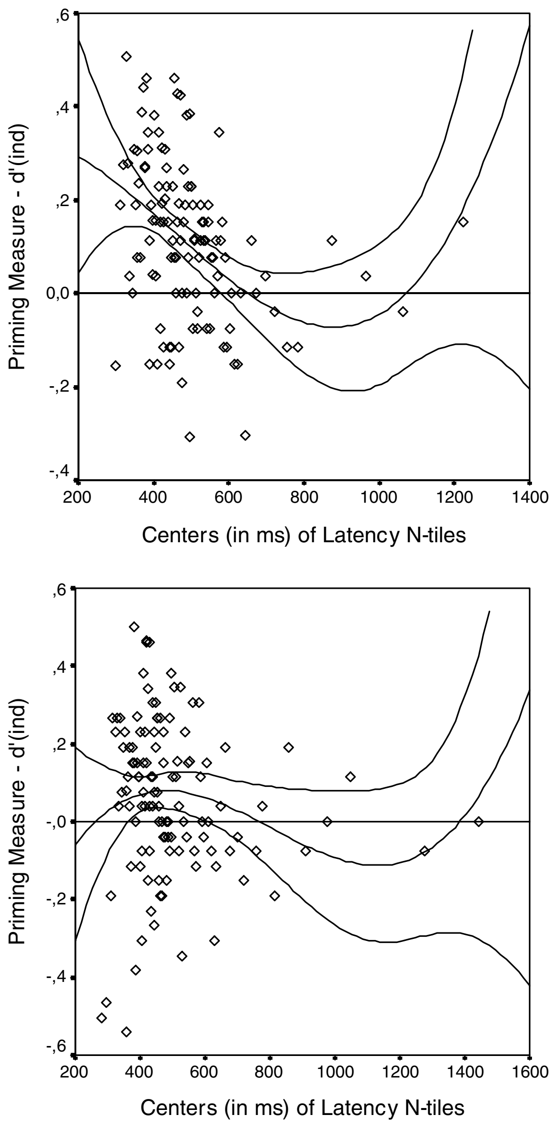

Fig. 2. Cubic regression plots for the effects of masked primes as a function of response latency (LOC functions) for the category congruency effects in Experiment 1 (upper panel) and Experiment 2 (lower panel). The regression plots are flanked by 95% confidence interval boundaries.

2.3. Discussion

The results were clear-cut. Novel word primes engendered significant category congruency effects even though there was more overlap at the word-fragment level between incongruent primes and targets than between congruent primes and targets in Experiment 1 and no overlap at all in letters or larger word fragments between primes and targets in Experiment 2.

In previous studies using similar procedures, category congruency effects were in the order of $d' = 0.40$ when words repeatedly classified as targets were employed as primes (e.g., Abrams & Greenwald, 2000; Draine & Greenwald, 1998). In contrast, in the present study, the priming effect was smaller ($d' = 0.12$ and $d' = 0.06$ in Experiment 1 and 2, respectively) confirming our expectation that a residual semantic priming effect of subliminally presented novel word primes might be relatively small and would consequently require larger samples of participants and priming trials than previously realized to be detected.

In previous studies using similar procedures, prime durations of 82 ms (as used here) and even somewhat smaller prime durations often led to d' values for prime visibility significantly larger than zero (e.g., Draine & Greenwald, 1998), which was not the case in the present studies. Note, however, that in contrast to previous studies, prime words were embedded in random consonants (e.g., 'fair' was presented as 'gkvtfairsmltr'). In addition, we used novel prime words, whereas the previous studies used prime words that had repeatedly been seen as targets prior to the test of prime visibility. Both of these differences are likely to decrease prime visibility in our studies relative to the previous studies.

In Experiment 3, we used more traditional presentation parameters and extended the results to another content domain, namely gender priming.

3. Experiment 3

In Experiment 3, targets and primes were first names, and participants' task was to decide whether the target name was male or female. Like in Experiment 2, there were two sets of stimuli which employed different letters. Half of the participants saw targets from Set 1, the other half saw targets from Set 2. Primes were always sampled from both word sets so that half of these were also seen as targets (practiced primes) and half were novel primes, defining the factor prime novelty. Unlike in Experiment 2, primes were not embedded in random consonants, and we used shorter prime durations (25 and 42 ms) along with a longer backward mask. Manipulating prime novelty allowed us to test one of the premises of the present work, namely that category congruency priming by novel primes is smaller than priming by practised primes.

3.1. Method

The procedures followed those of the first two experiments unless where explicitly mentioned otherwise. Prime duration (25 ms versus 42 ms) and word set was manipulated between participants. Prime novelty was manipulated within participants.

3.1.1. Participants

Participants were 112 University-of-Washington students. They were volunteers from the introductory psychology course who received an optional small course credit in exchange for participation. There were 28 participants in each prime duration times word set condition.[3]

3.1.2. Stimuli

Two word sets of 12 male and 12 female names each were used that are shown in Appendix A. Names from Set 1 employed the letters a, d, h, j, l, n, o, p, w, and y; names from Set 2 were composed of the letters b, c, e, g, i, k, m, r, s, t, u, v, x, and z. The names comprised between three and six letters. Primes were presented without being embedded in random consonants and in upper case. Targets were presented in lower case. In practice blocks, primes were replaced by the string 'XXXX'. Masks were eight bitmapped images composed of random letter fragments. Different images were always used as forward and backward mask on any given trial.

3.1.3. List Construction

Participants worked through blocks of 48 prime-target pairs. For half of the participants, words from Set 1 were used as targets; the other half saw words from Set 2 as targets. Words from both sets were used as primes in equal proportions so that blocks realized a balanced prime gender (male versus female) times target gender (male versus female) times prime novelty (novel versus practiced) design. Prime and target of a given pair were always different words.

[3] We slightly oversampled those conditions where we expected small category congruency effects so that there were actually between 28 and 36 participants in each group. The additional participants did not change any of the results, and we left them out for the present report in favour of analyzing a balanced between-participants design with 28 participants in each group.

3.1.4. Procedure

The sequence of events on priming and visibility-test trials was as follows: fixation cross, followed after 500 ms by a forward mask for 300 ms, prime for 25 or 42 ms depending upon the participant's prime-duration condition, followed by a backward mask and then the target. Prime-target SOA was 75 ms so that the duration of the backward mask was 50 ms in the 25 ms prime-duration group and 33 ms in the 42 ms prime-duration group. Like in the previous experiments, an exclamation mark signalled the response window during which participants were required to respond in the priming phase.

The priming phase and the visibility-test phase each consisted of three practice blocks followed by six experimental blocks. In the phase testing prime visibility, responses were accepted no sooner than 600 ms after target onset to discourage fast responses, potentially contaminated by category congruency priming. The practice phase for the visibility test began with larger prime durations than the nominal 25 or 42 ms that were successively shortened from block to block, reaching the nominal levels for the six experimental visibility-test blocks.

Participants were seated at a distance of about 60 cm from a 43 cm SVGA color monitor with 120 Hz refresh rate. Words were presented in a bold 24 pt font.

3.2. Results

For the analyses of the priming data, responses with latencies smaller than 100 ms or larger than 1000 ms were excluded thereby leaving out 1.9% of the data. Accuracy data and response latencies for correct responses are shown in Appendix B. The d' values for category congruency effects and prime visibility are shown in Table 2 along with the results of individual t tests for significance.

An analysis of variance of the category congruency effects with factors prime duration, prime novelty, and word set revealed an interaction of all three factors ($F(1, 108) = 6.77$, $p = .01$). Separate analyses for word set 1 and word set 2 showed main effects for prime duration ($F(1, 54) = 48.91$, $p = 10^{-9}$, and $F(1, 54) = 27.74$, $p = 10^{-6}$, respectively) and prime novelty ($F(1, 54) = 14.26$, $p = .0004$, and $F(1, 54) = 47.04$, $p = 10^{-8}$, respectively). As can be seen in Table 2, category congruency priming increased with prime duration and with practice in classifying prime words as targets. For the second word set, there was also an interaction of prime novelty and prime duration ($F(1, 54) = 17.41$, $p = .0001$), reflecting a particularly large category congruency effect of practiced primes presented for 42 ms (see Table 2).

The data for novel primes are the focus of the present paper. An analysis of variance of category congruency effects by novel primes with factors prime duration and practice set showed a main effect of prime duration ($F(1, 108) = 21.26$, $p = 10^{-5}$), but no significant effects involving word set (although the interaction of prime duration and word set approached significance, $F(1, 108) = 3.21$, $p = .08$). The category congruency effect for 25 ms primes was 0.01, $-1 < t < 1$; the effect for 42 ms primes was 0.19, and it was significant, $t(55) = 6.31$, $p = 10^{-8}$.

The mean d' value for prime visibility of 42 ms novel primes was $d' = 0.05$, and it was not significantly different from zero ($t(55) = 1.60$, $p = .12$). In a regression analysis, the category congruency effect by 42 ms novel

Table 2
d′ Values for category congruency effects (CCE) and prime visibility (PV) in experiment 3

Prime duration	Prime novelty	Word set	CCE		PV	
			M	*SD*	*M*	*SD*
25 ms	Novel	1	−0.03	0.16	0.03	0.19
		2	0.04	0.21	−0.04	0.23
	Practiced	1	0.09	0.24	0.02	0.21
		2	0.14*	0.18	0.04	0.21
42 ms	Novel	1	0.22*	0.19	0.04	0.24
		2	0.15*	0.25	0.06	0.23
	Practiced	1	0.38*	0.20	0.13*	0.29
		2	0.56*	0.27	0.07	0.21

* $p < .05$.

primes was regressed on prime visibility (Greenwald et al., 1995). The intercept was 0.18 ($SE = 0.03$), and it was significantly different from zero ($t(54) = 5.97$, $p = 10^{-8}$). The category congruency effect was not a function of prime visibility: the regression slope was 0.11 ($SE = 0.13$; $-1 < t < 1$). Moreover, neither the quadratic nor the cubic trend of prime visibility approached significance when these higher-order components were included in the regression equation (in both cases: $|t| < 1$) so that there was no evidence for a departure from linearity in the regression function. The improved regression method by Klauer et al. (1998) corroborated these results (i.e., there was a significant intercept and a non-significant slope).

An analysis by items with primes as units was performed to assess whether the category congruency effect by 42 ms novel primes generalizes over the different prime words or is focussed on a few unusual primes (Clark, 1973). Like in Experiments 1 and 2, the effect was found to generalize over primes ($M = 7.57\%$, $SD = 9.26\%$, $t(47) = 5.66$, $p = 10^{-6}$, see also Footnote 1). Finally, in terms of correct response latency (see Appendix B), the category congruency effect was 6.19 ms ($SD = 15.22$ ms), and it was significant ($t(55) = 3.04$, $p = .004$).

3.3. Discussion

In Experiment 3, masked category congruency priming of gender classifications was a function of prime duration and prime novelty. As expected, category congruency priming by novel primes was smaller than priming engendered by primes that are also seen as targets. In particular, for 25 ms primes, we replicated previously observed result patterns (Abrams & Greenwald, 2000; Damian, 2001; Kunde et al., 2003) inasmuch as a significant category congruency effect was observed for practiced primes, but not for novel primes (see Table 2). For 42 ms primes, however, even novel primes gave rise to a significant category congruency effect in the present study. Like in Experiment 2, novel prime words were composed of letters that did not appear in target words ruling out a non-semantic explanation of category congruency effects in terms of overlap in letters or word fragments.

The d' values for prime visibility were associated with p values of .14, .12, and .12 in Experiments 1, 2, and 3, respectively, suggesting that an increase in statistical test power (e.g., by collecting data from additional participants) might have revealed that there remained a small, but significant amount of prime visibility. There was however no relationship between the size of the category congruency effect and the measure of prime visibility in regression analyses of our data (see also Footnote 1). Nevertheless, in Experiment 4, we employed prime presentation parameters and mask durations that further reduced prime visibility.

As explained in the introduction, the results are difficult to account for by approaches that assume that the effects are driven by partial analyses of primes at the letter and word-fragment level. The findings are more easily explained by assuming that the prime words in the present experiments were processed semantically (e.g., Dehaene et al., 1998). However, like any empirical study, Experiments 1, 2, and 3 are subject to a number of criticisms. In Experiment 1, overlap between primes and targets in word fragments was counted independently of the position of the word fragment in the word. This amounts to assuming that all positions are equally important in engendering priming effects, an assumption that may be false (e.g., Perea & Lupker, 2003). For all experiments, it is difficult to refute the claim that low-level (e.g., sub-letter) visual features of the prime words may be confounded with prime valence or target valence or both and that these are responsible for subliminal category congruency effects although this is perhaps not a plausible claim when novel primes and practiced targets are from different subsets of the alphabet (Experiment 2) and are additionally presented in different letter cases (Experiment 3). In Experiment 4, we employed pictures as targets so that any overlap between primes and targets in orthographic features is eliminated at whatever level, rendering an account in terms of low-level visual features even more unlikely.

4. Experiment 4

In Experiment 4, targets were eight smileys and eight grumpeys shown in Fig. 3. Because participants in pilot tests were extremely fast in deciding whether a target was positive (smiley) or negative (grumpey), we presented the targets rotated clockwise by 90°. Black-and-white versions of the targets are shown in Fig. 3; the targets were actually presented in yellow and white with rare occurrences of the colors red and blue.

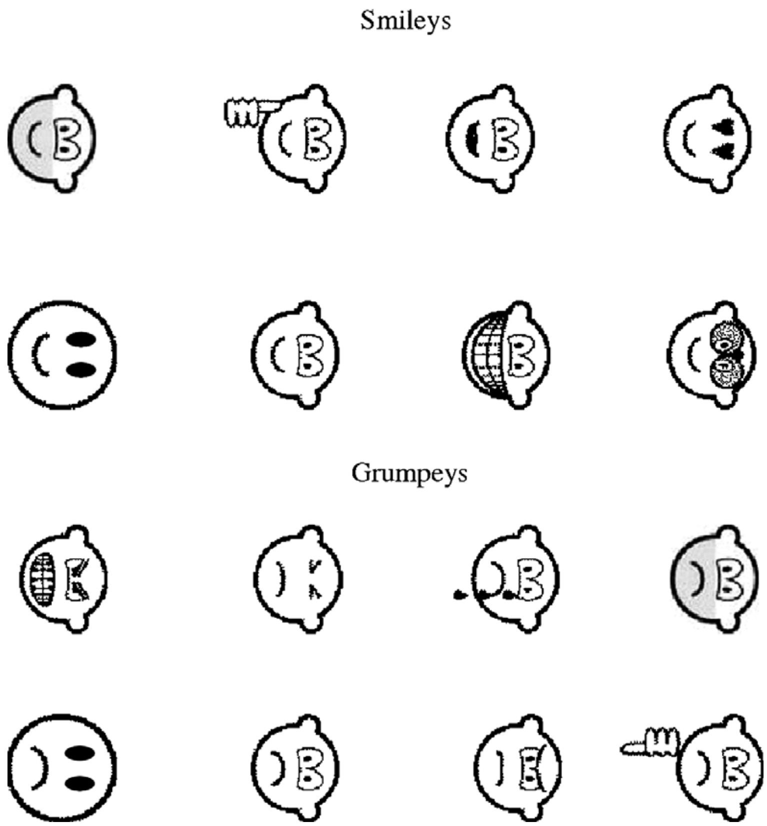

Fig. 3. Targets in Experiment 4.

Additional changes were that premask duration was increased to 353 ms, postmask duration was 23 ms, prime duration was 35 ms, and primes were again embedded in random consonants. Furthermore, an adaptive response window procedure was used, in which the window center was tailored to each participant's performance.

The more severe masking conditions, the shorter prime duration, and participants' high overall response speed (Hines, 1992; Hines, Czerwinski, Sawyer, & Dwyer, 1986; Williams, 1996) led us to expect smaller category congruency effects than observed in Experiments 1, 2, and 3. We therefore recruited twice as many participants as in each of Experiments 1 and 2.

4.1. Method

The procedures followed those of the first two experiments unless where explicitly mentioned otherwise.

4.1.1. Participants

Participants were 66 University-of-Bonn students who had not participated in Experiments 1 and 2. They received Euro 6 for participating.

4.1.2. Stimuli

Primes were the 70 positive and 70 negative words used as primes and targets in Experiment 1. Targets were the smileys and grumpeys shown in Fig. 3. On the screen, they measured 1.8 cm from ear to ear and 1.2 cm from chin to scalp.

4.1.3. Adaptive response window procedure

Because pilot testing suggested that participants were able to classify the targets very quickly, we used an adaptive response window procedure for the priming blocks, in which the window center was tailored to each participant's performance. The window center was initially set to 370 ms. Following Greenwald et al. (1996), the window center was adjusted after each block of 48 trials contingent on the participant's performance in that block: it was decreased by 33 ms, if in that block, there were no more than 20% errors and the mean response latency did not exceed the window center by more than 100 ms. It was increased by 33 ms, if there were 45% or more errors and the mean response latency exceeded the window center by more than 100 ms. If neither of these sets of conditions was met, the window center was not changed.

4.2. Results

For the analyses of the priming data, responses with latencies smaller than 100 ms or larger than 1000 ms were excluded thereby leaving out 1.9% of the data. Accuracy data and response latencies for correct responses are shown in Table 1. The category congruency effect was $d' = 0.03$ ($SD = 0.10$), and it was significantly larger than zero according to a one-tailed t test ($t(65) = 1.96$, $p = .027$).

The d' value for prime visibility was $d' = 0.00$ ($SD = .15$), and it was not significantly different from zero ($t(65) = 0.22$, $p = .82$). In a regression analysis, the category congruency effect was regressed on prime visibility (Greenwald et al., 1995). The intercept was 0.03 ($SE = 0.013$), and it was significantly different from zero ($t(64) = 1.97$, one-tailed $p = .027$). The category congruency effect was not a function of prime visibility: the regression slope was -0.05 ($SE = 0.09$; $-1 < t < 1$). Moreover, there was again no evidence for non-linearity in the regression analysis ($|t| < 1$ for both the quadratic and the cubic trend of prime visibility when these trends were included in the regression equation). The improved regression method by Klauer et al. (1998) attempts to control for measurement error in the estimates of prime visibility. In the present case, the method estimated both mean and variance of the true-score variable of prime visibility to equal zero. This underlines the effectiveness of the masking conditions, but makes it impossible to go on to perform a regression analysis with this true-score variable as predictor.

An analysis by items with primes as units was performed to assess whether the category congruency effect generalizes over the different prime words or is focussed on a few unusual primes (Clark, 1973). Like in Experiments 1 and 2, the effect was found to generalize over primes ($M = 1.00\%$, $SD = 5.45\%$, $t(139) = 2.08$, $p = .04$, see also Footnote 1). Finally, in terms of correct response latency (see Table 1), the categoy congruency effect was -1.72 ms ($SD = 10.58$ ms), and it was not significant ($t(65) = 1.32$, $p = .19$).

4.3. Discussion

In Experiment 4, there was not a trace of prime visibility; nevertheless significant category congruency priming emerged. The more severe masking and prime presentation conditions may have been responsible for the fact that the category congruency effect in Experiment 4 ($d' = 0.03$) was smaller than those observed in Experiments 1 ($d' = 0.12$) and 2 ($d' = 0.06$). As the prime duration approaches zero, any category congruency effect must of course diminish (see Experiment 3) and eventually vanish. An additional reason may lie in the choice of primes (words) and targets (pictures). For example, according to Masson and Bodner (2003), the similarity of the processing operations applied to a prime event and those applied to a target determine the extent to which target processing is affected by the prime. Because of the small size of the category congruency effect in this experiment, we nevertheless felt it prudent not to base any conclusion in the General Discussion solely on the results of Experiment 4.

Because targets were pictures rather than words, it is unlikely (a) that there was much overlap in perceptual features between primes and targets to begin with, (b) that any remaining overlap was systematically larger for congruent prime-target pairs than for incongruent prime-target pairs, and (c) that such differential overlap, if it existed, was responsible for the category congruency effect. Yet, as already noted several times, it is difficult to refute the perceptual-overlap hypothesis with certainty unless the class of relevant perceptual features is precisely circumscribed. In the present case, the feature that discriminates positive from negative targets most clearly is the shape of the mouth; in positive (rotated) targets it has the form of a "c", in negative targets it has the form of the mirror image of a "c". For each prime word, we counted the letters in which a c-like feature occurred (in the used font, Courier, these were the letters a, ä, e, c, d, g, and q) and in which its mirror image occurred as a feature (the letters b, p, and ß). We omitted the letters "o" and "ö" that combine both features in the shape of a circle. On average, the c-feature occurred in positive and negative primes 2.13 times ($SD = 1.19$) and 2.19 times ($SD = 1.08$), respectively; its mirror image 0.26 ($SD = 0.50$) and 0.39 ($SD = 0.57$) times. In an analysis of variance with factors feature (c versus its mirror image) and prime valence, the c-feature turned out to occur significantly more frequently than its mirror image in both positive and negative primes ($F(1,138) = 299.96$, $p = 10^{-36}$), but there were no effect or interactions involving prime valence (largest $F = 0.76$, smallest $p = .39$). This makes it unlikely that differential overlap between congruent versus incongruent primes and targets in these discriminating features is responsible for the observed category congruency effect. A reviewer suggested to restrict the analysis to the letters c, d, and q for the c-feature and b and p for its mirror image. Again, the c-feature occurred more frequently than its mirror image, $F(1,138) = 5.48$, $p = .02$, but there were no effect or interactions involving prime valence (largest $F = 2.86$, smallest $p = .09$).

5. General discussion

In a series of four experiments, category congruency priming was engendered by masked novel prime words. Thus, category congruency priming can be obtained on the basis of prime words that were never classified as targets. Given the power analyses reported in the introduction and considering the small sizes of some of the effects, it seems very likely that previous unsuccessful attempts to find the effect (Abrams & Greenwald, 2000; Experiment 3; Damian, 2001, Experiments 2 and 3) simply lacked statistical test power for detecting it.

Prime visibility was measured by participants' ability to discriminate positive from negative masked primes. The d' values for prime visibility were small, in the lower range of the values reported in previous work in the field, and not significantly different from zero; nor was prime visibility related to the size of the category congruency effect in regression analyses. For each experiment, separate analyses defended the results against the hypotheses that the category congruency effects were caused by a few especially perceptive participants or by a few especially perceptible primes.[4] The latency operating characteristic functions of these effects (see Fig. 2 and Footnote 2) showed the characteristic shape (Abrams, 2005; Greenwald et al., 2003) with maximum priming at the fastest latencies and a dip below zero at longer latencies.

Can category congruency priming by novel primes be explained in terms of low-level perceptual analyses of primes? As discussed in the introduction, doing so presupposes that the amount of overlap between congruent primes and targets in relevant low-level perceptual features is larger than that between incongruent primes and targets. Experiments 1 to 3 attempted to control for different types of overlap. Experiment 1 controlled for the amount of overlap in terms of word fragments; in Experiments 2 and 3, any overlap between primes and targets in terms of individual letters was eliminated. In Experiment 4, targets were pictures, rendering an account in terms of perceptual overlap even more implausible because there was little perceptual similarity of any kind between prime words and target pictures to begin with. Although this series of experiments rules out many versions of the overlap hypothesis, it is perhaps impossible to refute the hypothesis once and for all unless the realm of potentially relevant features is completely known.

Turning to the different accounts mentioned in the introduction, the present findings do not undermine any of the various theories that have been offered for category congruency priming that occurs for primes that have been practice-classified as targets, and as elaborated below, we believe that the mechanisms described in these theories can and do contribute to category congruency effects for practiced primes. Some of the accounts cannot however easily explain priming by novel masked primes.

[4] In further control analyses suggested by a reviewer, we excluded all participants with d' values for prime visibility larger than zero. Although the elimination of these participants entailed a considerable loss in test power, many of the priming effects remained significant. In Experiments 1, 15 of originally 33 participants remained in the analysis, yielding a significant priming effect, $t(14) = 6.04$, $p = 10^{-7}$. In Experiment 2, 12 of 33 participants were included, yielding an almost significant priming effect, $t(11) = 2.18$, $p = .052$. In Experiment 3, 25 of 56 participants in the condition with SOA 42 ms and novel primes remained in the analysis, yielding a significant priming effect, $t(24) = 3.23$, $p = .004$. In Experiment 4, 30 of 66 participants remained in the control analysis; the priming effect for these was descriptively almost as large as that for participants with visibility d' values above zero, but it was not significant, $t(29) = 1.14$, $p = .26$, very likely due to the loss in test power that is entailed by excluding half of the sample of participants.

According to the account by Dehaene et al. (1998) participants apply the task set for target processing to primes, leading to category congruency priming. The present results are consistent with this and other accounts that permit semantic processing of subliminal words (e.g., Masson & Bodner, 2003). Note that to explain the results of Experiment 4, the concept of a task set would have to be defined so flexibly that a task set for evaluating pictures can also be applied to extracting the valence of words.

Other accounts cannot readily explain category congruency priming by novel masked primes. For example, in the original version of the evolving-automaticity account (Damian, 2001; see also Abrams & Greenwald, 2000), subliminal category congruency effects are predicted only if primes were previously classified as targets. But in all four experiments reported here, priming was observed with primes that were never seen as targets.

Abrams and Greenwald (2000) showed that it is sufficient that primes contain word fragments of previously seen targets. Similarly, according to Kouider and Dupoux (2004), participants can sometimes reconstruct the full prime word from letters or word fragments that are perceived despite of the masks. In this view, the observed category congruency effects are actually effects of fully conscious, reconstructed primes. Both accounts encounter difficulties in explaining the present effects, because overlap between primes and targets at the letter and word-fragment level was controlled for (Experiment 1) or non-existent (Experiments 2, 3, and 4). In addition, if participants were able to reconstruct prime identity on a regular basis, leading to category congruency effects, a significant amount of prime visibility should a fortiori have been seen. Prime visibility was however non-significant in all four experiments.

The action-trigger hypothesis (Kunde et al., 2003) can in principle deal with the first three experiments reported here, if it is assumed that participants form action triggers for all possible positive and negative words (all possible male and female first names) in semantically elaborating the task instructions, an assumption that Kunde et al. (2003) themselves consider unlikely. Note that some of the first names in Experiment 3 such as John and Tim were relatively common and thereby perhaps predictable, making it somewhat more plausible for Experiment 3 than for the first two experiments that action-trigger templates might have been formed for some of the novel primes in elaborating the task instructions. On the other hand, it is even more unlikely that participants asked to evaluate pictures set up action triggers for each and every positive and negative word despite the fact that they never suspect that they will be asked to evaluate words (Experiment 4). Taken together, the present experiments speak against the action-trigger account as the sole basis of subliminal category congruency effects.

One point of departure for the present studies was a study by Klauer et al. (in press; see also Reynvoet et al., 2005, for a similar approach). In this study, the authors presented valenced adjectives and first names as primes and targets. Participants decided whether the adjectives were positively or negatively valenced and whether the names were male or female. Both kinds of decisions were to be indicated by the same two response keys. Targets were preceded by adjective or name primes associated with responses that either matched or mismatched the correct response to the target.

Prime and target could thus be associated with the same task (e.g., adjective-adjective pairs) or different tasks (e.g., adjective-name pairs). Two kinds of category congruency effects could thereby be isolated. Response-related priming was assessed as the size of the advantage that accrues to targets in different-tasks pairs by being preceded by primes associated with the same rather than the other response. So-called central priming was assessed as the increase in this congruency effect that was observed for same-task pairs over and above different-tasks pairs, that is as the additional priming that accrues due to prime and target sharing the same semantic category. The major findings were that response-related priming was much more pronounced than central priming, and that response-related priming, but not central priming, was modulated by prime visibility and prime and target repetition. In particular as the frequency with which individual words appeared as primes and targets was decreased, response-related priming, but not central priming, decreased.

Response-related priming, and its dependence on repetition and prime visibility, is well explained by mechanisms such as evolving automaticity (Abrams & Greenwald, 2000; Damian, 2001), reconstruction of prime identity from word fragments (Kouider & Dupoux, 2004), or the formation of action triggers (Kunde et al., 2003). The small residual central priming effect going back to shared membership in the same semantic category (e.g., the category of positive words) is less easily accounted for by these approaches. The fact that the central component was not a function of prime and target repetition led us to extrapolate that a residual *semantic* congruency effect might remain even when primes were never previously seen as targets. The present experiments confirmed this expectation.

What are the mechanisms underlying the residual semantic congruency effect in category congruency priming? One possibility, suggested by the large literature on semantic priming (e.g., Lucas, 2000), is that prime words can facilitate encoding or lexical access for semantically related targets, including categorically related targets (but see Hutchison, 2003). There is however little evidence for priming by irrelevant categorical relationships between prime and target in category congruency priming (Klauer & Musch, 2002, 2003). For example, there is little effect of whether or not prime and target both refer to animate objects in the valence-classification task. In concluding, we submit the speculation that the semantic congruency effect reflects facilitation in categorizing targets. In this analysis, the task set for target processing is applied to primes (Dehaene et al., 1998), leading to activation of the prime's task-relevant category (e.g., the category "positive" in the valence-classification task). This preactivation helps the categorization of a target of that same category, leading to central priming for such targets. Thus, prime-derived and target-derived bits of information interact at the stage of categorizing the target in one of the response categories rather than at the response-selection stage (as in response-related priming) or at the stage of encoding or lexical access. Specifically, a prime word might activate the mental representation of its task-relevant category (e.g., the category "positive"), thereby facilitating the categorization of congruent targets as exemplars of this same category, or hindering the categorization of incongruent targets as exemplars of the other category (e.g., the category "negative").

Taken together, we believe that masked category congruency priming comprises at least two components, a response-related component that depends on the extent to which the same words appear repeatedly as primes and targets and on the extent to which prime words or fragments thereof are visible, plus a less context-dependent but small semantic component that was the focus of the present paper. This multiple-components view of masked category congruency priming explains why category congruency effects have frequently been larger than those observed here. For example, when targets later appear as primes, response-related priming is expected to boost the overall masked category congruency effect as observed in Experiment 3. Conversely, when perceptual overlap between primes and targets is intentionally or incidentally reduced as when novel prime words from potentially large stimulus pools are used, the overall masked category congruency effect is likely to reflect only the semantic component. In such cases, overall masked category congruency priming is expected to be smaller and more difficult to detect.

The purpose of the present paper was to demonstrate the theoretically important effect of masked category congruency priming by novel prime words. The effect was found in four experiments that additionally controlled for a number of possible non-semantic alternative explanations, suggesting that semantic processing of prime words contributes to masked category congruency priming.

Appendix A

A.1. Experiment 1

A.1.1. Positive primes

aktiv [active], angenehm [comfortable], begabt [talented], denkfähig [thoughtful], engagiert [motivated], entspannt [relaxed], fair [fair], fleißig [assiduous], frei [free], froh [glad], gebildet [cultivated], gerecht [just], großzügig [magnanimous], heiter [cheerful], human [human], ideal [ideal], klug [clever], kreativ [creative], lebhaft [vivacious], munter [alert], offen [open], optimal [optimal], originell [original], sanft [tender], sonnig [sunny], sozial [prosocial], spontan [spontaneous], tolerant [tolerant], treu [faithful], vergnügt [enjoying], wahr [true], warm [warm], weise [wise], witzig [funny], and zart [tender].

A.1.2. Negative primes

aalglatt [slippery], arrogant [arrogant], beklommen [anxious], bockig [stubborn], blöd [stupid], böse [evil], brutal [brutal], dumm [stupid], feige [cowardly], fies [mean], gemein [nasty], geizig [stingy], giftig [poisonous], grausam [cruel], grob [rude], indiskret [indiscreet], kalt [cold], kaputt [malfunctioning], korrupt [corrupt], miserable [miserable], monoton [monotone], negativ [negative], pickelig [pimpled], prüde [prudish], roh [rough], rüde [rude], spießig [bourgeois], tot [dead], träge [inert], ungerecht [unjust], unfair [unfair], unsozial [antisocial], verhasst [hateful], verlogen [mendacious], and willenlos [irresolute].

A.1.3. Positive targets

anziehend [attractive], belesen [well-read], beliebt [popular], beständig [constant], ehrlich [honest], flexibel [flexible], freudig [joyful], friedlich [peaceful], fröhlich [cheerful], geduldig [patient], geistvoll [profound], gemütlich [jolly], geschickt [skillful], gesellig [sociable], gesund [healthy], glücklich [happy], gut [good], gutherzig [kind-hearted], gutmütig [good-natured], gutwillig [willing], herzlich [cordial], humorvoll [humorous], kuschelig [cosy], lebendig [alive], lieb [nice], lustig [funny], natürlich [natural], mutig [courageous], schön [beautiful], sensibel [sensitive], sicher [safe], sinnlich [sensuous], verliebt [amorous], zufrieden [satisfied], and zärtlich [tender].

A.1.4. Negative targets

abstoßend [disgusting], abweisend [unfriendly], aggressiv [agressive], anmaßend [presumptuous], arglistig [crafty], blasiert [blasé], borniert [narrow-minded], boshaft [malicious], eisig [icy], ekelhaft [distasteful], falsch [false], gehässig [spiteful], geistlos [spiritless], gierig [greedy], habgierig [greedy], herrisch [imperious], jähzornig [hot-tempered], lästig [burdensome], morsch [rotten], neidisch [jealous], passiv [passive], peinlich [embarassing], rüpelhaft [boorish], schlampig [untidy], schlecht [bad], schmutzig [dirty], schuldig [guilty], täppisch [clumsy], tödlich [deadly], unehrlich [dishonest], unsicher [unsure], wehleidig [snivelling], widerlich [repulsive], zänkisch [quarrelsome], and zwanghaft [obsessive].

A.2. Experiment 2

A.2.1. Set 1, positive words

ananas [pine-apple], anbau [cultivation], baby [baby], bach [brook], buch [book], bunt [colourful], fachbuch [specialized book], haut [skin], hautnah [close to the skin], hübsch [nice], jacht [yacht], jazz [jazz], nah [near], sachbuch [subject book], sacht [gentle], saft [juice], sanft [soft], sauna [sauna], schatz [treasure], schön [beautiful], schöntun [flatter], schuss [shot], substanz [substance], and tanz [dance].

A.2.2. Set 1, negative words

aas [carcass], abschuss [shooting], aus [out], aussatz [leprosy], autsch [ouch], bös [nasty], faust [fist], futsch [gone], habsucht [greediness], hass [hate], quatsch [non-sense], satan [satan], schuss [shot], schutt [rubbish], staub [dust], suff [booze], tabu [taboo], taub [deaf], unnütz [useless], unsanft [rough], unstatthaft [inappropriate], untat [crime], unzucht [lewdness], and zuchthaus [prison].

A.2.3. Set 2, positive words

erde [earth], gemälde [painting], gold [gold], idee [idea], idol [idol], kleid [dress], komik [humour], lied [song], lilie [lily], logik [logic], meer [sea], melodie [melody], mild [mild], milde [mildness], perle [pearl], prämie [award], premiere [opening], privileg [privilege], pro [pros], rekord [record], vogel [bird], wärme [heat], welpe [puppy], and wiege [cradle].

A.2.4. Set 2, negative words

ärger [annoyance], droge [drug], eklig [disgusting], erreger [pathogen], geier [vulture], gierig [greedy], grimmig [grim], grippe [influenza], groll [grudge], irre [crazy], kerker [dungeon], killer [killer], kippe [stub], krieg [war], moder [mould], mord [murder], mordgier [bloodthirstiness], mordgierig [bloodthirsty], rempelei [jostling], verlierer [looser], viper [viper], widerwillig [unwilling], widrig [adverse], and wirr [confused].

A.3. Experiment 3

A.3.1. Set 1, female names

Joan, Donna, Dawn, Lola, Polly, Wanda, Anna, Hannah, Holly, Ann, Nora, and Wynona.

A.3.2. Set 1, male names

John, Jonah, Andy, Dan, Alan, Wally, Noah, Dylan, Nolan, Ladd, Jay, and Donald.

A.3.3. Set 2, female names

Eve, Meg, Susie, Iris, Tess, Sue, Vicki, Bess, Mimi, Teri, Keri, and Trixie.

A.3.4. Set 2, male names

Eric, Curt, Tim, Mike, Russ, Kirk, Merv, Burt, Steve, Zeke, Rick, and Emmet.

Appendix B

Accuracy (in percent) and response latencies (ms) for correct responses in Experiment 3

Prime duration	Prime novelty	Word set		Incongruent		Congruent	
				M	*SD*	*M*	*SD*
25 ms	Novel	1	Accuracy	78	10	77	9
			Latency	450	38	449	39
		2	Accuracy	75	8	77	8
			Latency	435	28	429	25
	Practiced	1	Accuracy	74	9	78	11
			Latency	453	39	449	38
		2	Accuracy	72	8	78	7
			Latency	441	30	431	29
42 ms	Novel	1	Accuracy	70	8	79	8
			Latency	446	41	439	44
		2	Accuracy	70	9	77	12
			Latency	440	55	435	57
	Practiced	1	Accuracy	65	10	80	7
			Latency	458	41	435	47
		2	Accuracy	60	9	82	8
			Latency	450	58	424	60

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