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Unconscious priming according to multiple S-R rules[☆], [☆☆]

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Abstract

The present study investigated if unconscious primes can be processed according to different stimulus-response (S-R) rules simultaneously. Participants performed two different S-R rules, such as judging a digit as smaller or larger than five and judging a letter as vowel or consonant. These S-R rules were administered in random order and announced by a previously presented cue. Each target stimulus was preceded by subliminal primes which afforded a different or an identical response according to either the currently irrelevant or currently relevant S-R rule. In three experiments, we consistently found priming effects according to currently irrelevant S-R rules, even when primes for the relevant and irrelevant S-R rules were presented simultaneously. Thus, unconscious stimuli have the power to activate responses according to currently required and currently not required S-R rules concurrently. The results are in line with response activation accounts of subliminal priming and suggest that at least two routes may gain access on response processes simultaneously.

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1. Introduction

Unconscious stimuli can bias behavior. A well-established demonstration is subliminal priming. In a typical subliminal priming experiment participants perform a two choice reaction time task, like categorizing whether a presented digit is smaller or larger than five. Prior to the target another stimulus, the so-called prime is presented that is embedded in masks to avoid conscious processing. If this prime affords the same response as the target, it is a congruent prime. If it affords another response than the target, it is an incongruent prime. Typically, RTs and error rates are increased for incongruent compared to congruent primes, indicating that the primes activate their assigned responses despite participants being unaware of it.

Early work on subliminal priming primarily aimed at safeguarding unconscious priming effects against alternative accounts, such as influences of residual conscious prime perception. It turned out that unconscious priming is indeed a robust phenomenon and can be obtained in a variety of tasks (Marcel, 1980; Neumann & Klotz, 1994). Consequently interest shifted from establishing the phenomenon towards identifying the mechanism and the necessary preconditions of unconscious priming.

Concerning the mechanisms of unconscious priming, there is convincing evidence that subliminally presented primes affect response generation. The most convincing evidence for this notion was provided by LRP studies. LRPs (lateralized readiness potentials) are EEG potentials that indicate left vs. right hand response preparation. Several recent studies (Dehaene et al., 1998; Eimer, 1999; Eimer & Schlaghecken, 1998, 2003) have shown that subliminal primes have the power to trigger LRPs, indicating that they indeed cause response preparation which in turn may facilitate or delay the response required by the subsequently presented target. This response priming might be either mediated by direct motor activation or by the activation of more abstract response codes like “left” vs. “right” which are to be applied to different motor effectors (cf. Abrams, Klinger, & Greenwald, 2002; Reynvoet, Gevers, & Caessens, 2005).

Considerable progress has been made on exploring the preconditions for unconscious priming as well. For example, it has been shown that stimuli, though being invisible, need to be attended to in order to be effective (Naccache, Blandin, & Dehaene, 2002). Furthermore, unconscious primes probably are only processed according to currently active intentions (Ansorge, Heumann, & Scharlau, 2002) and the primes have to be expected by the actor to some extent in order to bias behavior unconsciously (Kunde, Kiesel, & Hoffmann, 2003).

Although the understanding of unconscious priming processes has progressed remarkably there remain a couple unsolved issues. For example, there is still a controversial debate on whether primes activate semantic categories or just response codes. Whereas some results suggest that unconscious primes bias responding without access to semantic codes (e.g. Damian, 2001) there is evidence in favor of semantic pathways as well (Dehaene et al., 1998; Reynvoet et al., 2005). Although the present study was not designed to address this issue, we will return to potential implications of our data to this debate in the General discussion.

The present study aimed at elaborating on another issue namely to what extent unconscious priming is restricted to a fixed stimulus-response (S-R) rule. In its simplest form this prerequisite seems almost self-evident. Of course, stimuli (be they conscious or unconscious) can activate responses only to the extent that they are clearly assigned to a certain response. Accordingly, almost all existing studies on subliminal priming relied on settings in which participants performed a two choice reaction time task. For example participants have been instructed to indicate whether a target stimulus appeared on the left or right side (Ansorge et al., 2002; Klotz & Neumann, 1999), whether a string of letters is a word or a non-word (Klinger, Burton, & Pitts, 2000), whether a digit is smaller or larger than five (Dehaene et al., 1998), whether an object is pleasant or unpleasant (Abrams et al., 2002; Draine & Greenwald, 1998), or larger or smaller than a reference object (Damian, 2001).

However, it is not uncommon in everyday life as well as in psychological experiments that actors have to maintain several S-R rules more or less concurrently. A well-established example for a corresponding experimental paradigm is task-switching (Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995). In a typical task-switching experiment participants switch between different S-R rules in a trial by trial manner. For example, in one trial a digit has to be judged as smaller or larger than five, whereas in the next trial a digit has to be judged as odd or even. In the present study, we apply this methodology to explore whether unconscious stimuli are processed according to currently required S-R rules exclusively, or if unconscious primes have the power to activate responses according to other S-R rules (applied recently or to be applied soon) as well.

To our knowledge, there is only one study by Neumann and Klotz (1994, Exp. 4) that investigated subliminal priming effects under conditions of changing S-R rules. Participants were to press a left or right response key to indicate the location of a target stimulus. A prime was presented prior to the target either in the same or another location as the target resulting in congruent vs. incongruent primes. An additional cue was presented prior to prime and target stimuli to instruct participants whether the S-R mapping was compatible (i.e. press left key if the target is on the left side and right key if the target is on the right side) or incompatible (i.e. press left key if the target is on the right side and right key if the target is on the left side). The cue and therewith the S-R rules were chosen randomly from trial to trial. Data revealed reliable prime congruency effects according to the currently required S-R rule with a sufficiently long cue-to-stimulus-interval (reliable priming effects were observed for cue-to-stimulus-intervals of 750 and 1250 ms, but not for 250 ms), indicating that subliminal priming effects can flexibly adapt to currently required S-R mappings. Thus for example, if the compatible S-R rule was required a left prime facilitated a left response but if the incompatible rule was required the same prime facilitated a right response. As the two S-R mappings were contradictory, i.e. the one was the reversal of the other, the study showed adaptation to the currently relevant mapping but did not allow to assess whether at all and to what extent the primes still may have been processed according to the currently irrelevant S-R rule. The present experiments were designed in order to elucidate this issue. We are going to explore to what extent unconscious primes have access to responses according to more than only the currently required S-R rules.

2. Overview of experiments

Participants were instructed to either categorize a digit as smaller or larger than five or a letter as consonant or vowel. The digit and letter stimuli were administered in random order. In each trial, an auditory cue signalled which stimulus type will be presented and thus which S-R rules will be required. In Experiment 1, the presented primes always belonged to the currently not required S-R rules, i.e. a letter prime was presented when participants categorized digits and a digit prime was presented when participants categorized letters. We were interested in whether a subliminally presented prime can evoke a priming effect when participants currently apply a different S-R rule. In Experiment 2, the primes belonged either to the currently required or to the currently not required S-R rules. Thus, we were able to compare the size of the priming effect for both conditions. In Experiment 3 always two primes, a letter and a digit were presented in each trial to test whether two priming effects can occur concurrently. To anticipate the main result, reliable priming effects according to currently not required S-R rules were observed in each experiment.

3. Experiment 1

Participants were to categorize a digit as smaller or larger than five or to categorize a letter as consonant or vowel by pressing one of two possible response keys. Prior to the target, a subliminal prime of the currently *irrelevant* stimulus type was presented, i.e. when the "smaller or larger than five" classification was required, a letter was presented as prime and vice versa. As both stimulus types required pressing one of the same two response keys, the subliminally presented prime is either congruent, i.e. it would require the same response as the target or it is incongruent, i.e. it would require the alternative response as the target. The stimulus types and thus the required S-R rules were administered in random order and announced trial-by-trial by an auditory cue. We were interested in whether the subliminally presented primes evoke a congruency effect despite they do not fit to the currently performed S-R rules.

3.1. Method

3.1.1. Participants

Sixteen volunteers (aged 18–27) took part each in an individual session of approximately 60 min 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.

3.1.2. Apparatus and stimuli

An IBM-compatible computer with a 17 inch VGA-Display was used for stimulus presentation and response sampling. Stimulus presentation was synchronized with the vertical retraces of a 70-Hz monitor, resulting in a vertical refresh rate of approximately 14.5 ms. Responses were executed with the index fingers of both hands and collected with an external keyboard with three response keys (1.7 cm width, distance 0.2 cm), the middle response key was not used.

The digits 2, 3, 7, and 8 and the letters A, E, G, and H were used as primes and targets. The primes were presented for 2 refresh cycles of the display, i.e. 29 ms. They were preceded and followed by a random mask consisting of 3 symbols (possible were §, $, %, &, ?, and #) with a duration of 72 ms. The target was presented for 200 ms immediately following the post-mask. All characters were presented in sans serif font in white on dark-grey background; each character was approximately 1 cm high and 0.8 cm wide.

3.1.3. Design and procedure

Each trial started with an auditory cue (200 or 800 Hz) that indicated the currently relevant S-R rule. After 1000 ms the stimulus consisting of pre-mask, prime, post-mask, and target was presented. Response times were recorded from the onset of the target until the onset of the response. The next trial started 150 ms after response onset. Errors were indicated by a beep, and an additional interval of 850 ms elapsed before the next trial started.

Participants first practiced the S-R rules until they were able to perform both target-response-mappings by rote (they performed one or two training blocks with 24 trials each). The experiment consisted of 1024 trials in which each combination of S-R rules in trial n (2) × S-R rules in trial $n-1$ (2) × target in n (4) × target in $n-1$ (4) × prime in n (4) × prime in $n-1$ (4) was presented once. After every 96th trial, participants were allowed to take a short break. At the beginning of the experiment and after each break four randomly chosen trials served as warm-up trials. The S-R mappings for both tasks, that is whether to press the left or right key when the target was smaller or larger than five and whether to press the left or right key when the target was a consonant or vowel, were counter-balanced over participants as well as whether the high- or low-pitched tone indicated the presentation of a digit or a letter.

After the experiment, participants performed a detection task to test whether they were able to consciously recognize the primes. Participants were fully informed about the precise structure of the prime stimuli and were then presented with 192 trials identical to the experimental trials. In half of the trials the neutral symbol "&" was presented. Participants were to discriminate whether a prime or the neutral symbol had been presented by pressing the 1 or the 0 of the number keyboard. When they indicated to have seen a prime, they were additionally asked to identify it by pressing the corresponding key of the standard keyboard.

3.2. Results

3.2.1. Congruency effect

Trials with computer errors (0.02%) and trials with RTs deviating more than 3 standard deviations from the mean RT of each participant (1.0%) were excluded.

Additionally, trials after errors (5.0%) were excluded. RTs for correct trials and percentages of error (PEs) were averaged for each participant and congruent or incongruent primes.

t-tests revealed that participants responded faster and more accurately when the subliminally presented prime was congruent, i.e. it would require the same response as the target (475 ms and 4.5%) compared to incongruent, i.e. it would require the alternative response as the target (483 ms and 5.8%), RTs: $t(15) = 4.0$, $p < .001$, errors: $t(15) = 2.5$, $p < .05$.

A second analysis was computed to check whether the primes triggered congruency effects only when the current prime belonged to the S-R rule of the immediately preceding trial. Therefore, the factor repetition vs. switch of the S-R rules (e.g. letter task in $n-1$ and letter task in n vs. letter task in $n-1$ and digit task in n) was considered additionally to the factor prime congruency. If a prime were only effective when it belonged to the S-R rule that has been performed in the preceding trial, congruency effects would be restricted to switches of S-R rules (as the prime always belongs to the currently irrelevant S-R rule). An ANOVA on RTs revealed significant main effects of the factor repetition vs. switch of the S-R rule, $F(1,15) = 10.1$, $p < .01$, MSE = 11,340.8, and the factor prime congruency, $F(1,15) = 14.9$, $p < .01$, MSE = 926.4. The interaction between both factors was not significant, $F(1,15) < 1$, $p = .48$. The congruency effect amounted to 8 ms in repetition trials and 7 ms in switch trials. The same ANOVA on error rates showed significant main effects of the factor repetition vs. switch of the S-R rule, $F(1,15) = 20.6$, $p < .001$, MSE = 67.4, and the factor prime congruency, $F(1,15) = 7.2$, $p < .05$, MSE = 25.4. The interaction between both factors was not significant, $F(1,15) < 1$, $p = .40$. The congruency effect was 1.0% in repetition trials and 1.5% in switch trials. Thus, repetitions of S-R rules resulted in smaller RTs and fewer errors (467 ms and 4.1%) than switches of S-R rules (494 ms and 6.1%) but this factor had no impact on the observed congruency effects.

3.2.2. *Prime visibility*

To compute the signal detection value d', the correction of Hautus (1995) was applied if participants had 0% or 100% hits or false alarms. Participants' discrimination performance for neutral vs. non-neutral primes was $d' = .20$ (the mean hit rate was 58.6%, the mean false alarm rate was 50.4%) and deviated from zero, $t(15) = 2.7$, $p < .05$. The identification rate for the prime numbers and letters was 14.5% (chance level is 12.5%, as participants were instructed that the prime always belonged to the currently irrelevant S-R rules). The rate of correct prime identifications was not significantly different from chance level ($t(15) = 1.4$, $p > .18$).

To test whether the priming effect is related to the prime visibility, a regression analysis as proposed by Draine and Greenwald (1998, see also Greenwald, Klinger, & Schuh, 1995; Greenwald, Draine, & Abrams, 1996) was computed. A priming index was calculated for each participant, with index = 100 × (RT incongruent − RT congruent)/RT congruent. Individual priming indices were regressed onto individual d' values. The linear regression analysis revealed no significant correlation between d' and the priming index ($r = .027$, $F(1,15) = .01$, $p = .92$). The intercept of the regression was larger than zero (intercept = 1.74, $t(15) = 3.1$, $p < .01$), indicating that a significant priming effect is associated with d' of zero. Thus, the observed priming effect is independent on individual prime visibility.

3.3. Discussion

Participants randomly switched between either categorizing a digit as smaller or larger than five or a letter as consonant or vowel. Nevertheless, primes from the currently irrelevant S-R rules, that is stimuli to which participants currently do not have to respond, were clearly effective: Participants responded significantly faster and more accurately for congruent compared to incongruent primes. Thus, a priming effect according to currently irrelevant S-R rules was observed. This effect did not depend on whether the S-R rule of the previous trial was repeated or switched, thus the priming effect is independent on the type of the previously performed S-R rule. Consequently, the congruency effect according to the irrelevant S-R rule is not only a passive aftereffect of having used this rule in the preceding trial.

As the size of the effect is rather small (8 ms in RTs and 1.3% in error rates) we were interested in first replicating the effect in another experiment and second comparing the effect size with priming effects from relevant S-R rules.

4. Experiment 2

The second experiment was conducted to compare the size of congruency effects for primes that do not fit the currently performed S-R rules to primes that do fit. Again participants categorized a digit as smaller or larger than five or a letter as consonant or vowel. The prime that was presented prior to the target was a letter in 50% of all trials and a digit in the other 50%. Thus, in half of the trials the prime belonged to the currently instructed S-R rules whereas in the other half it belonged to the currently irrelevant S-R rules.

4.1. Method

4.1.1. Participants

Sixteen volunteers (aged 19–30) took part each in an individual session of approximately 60 min 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.

4.1.2. Apparatus and stimuli

An IBM-compatible computer with a 17 inch VGA-Display and the software package E-Prime (Schneider, Eschman, & Zuccolotto, 2002) was used for stimulus presentation and response sampling. Stimulus presentation was synchronized with the vertical retraces of the 60-Hz monitor, resulting in a refresh rate of 16.7 ms. Responses were executed with the index fingers of both hands and collected with the "1" and "3" key of the number pad of a standard keyboard.

The digits 2, 3, 7, and 8 and the letters A, E, G, and H were used as primes and targets. The masks consisted of five randomly chosen symbols (out of §, $, %, &, ?, and #). The primes were presented for 33 ms (2 refresh cycles of the display), the masks for 83 ms (5 refresh cycles), and the targets for 200 ms. All characters were presented in font Arial, point size 48, in white on a black background.

4.1.3. Design and procedure

The trial procedure was identical to Experiment 1, except that no additional post error interval was inserted.

After 32 practice trials, participants performed 8 blocks in which each combination of S-R rules (2) × target (4) × prime (8) was realized twice, resulting in a total of 1024 trials (2 trials × 2 S-R rules × 4 targets × 8 primes × 8 blocks). The first trial in each block was considered a warm-up trial and did not enter statistical analysis. The response-mappings for both S-R rules and the mapping of the auditory cue (200 Hz vs. 800 Hz) to target type (digits vs. letters) were counter-balanced across participants.

The detection task that was performed after the experiment consisted of 128 trials similar to the experimental trials except that in half of the trials the neutral symbol 0 was presented instead of a prime. Participants were fully informed about the precise structure of the prime stimuli and were asked to indicate which prime was presented by pressing the corresponding key.

4.2. Results

4.2.1. Congruency effects

Trials with RTs deviating more than 3 standard deviations from the mean RT of each participant (1.5%) and trials following an error (5.7%) were excluded. RTs for correct trials and percentages of error (PEs) were averaged for each participant and each combination of the factors prime congruency (congruent or incongruent) and type of prime (fitting the currently relevant S-R rule or fitting the currently irrelevant S-R rule).

Mean RTs and error rates depending on the factors prime congruency and type of prime (fitting to the currently relevant or the irrelevant S-R rule) are presented in Table 1. An ANOVA on mean RTs with the within-subject factors prime congruency

Table 1
Mean RTs and percentages of errors (*SD* in brackets) depending on prime congruency and type of prime

Prime congruency	Prime fits to			
	Relevant S-R rule		Irrelevant S-R rule	
	RT in ms	PE	RT	PE
Congruent	495 (16.4)	5.1 (.88)	505 (15.9)	5.8 (.99)
Incongruent	504 (15.2)	6.9 (1.1)	510 (15.2)	6.1 (.98)

and type of prime revealed significant main effects of the factor prime congruency, $F(1,15) = 10.8$, $p < .01$, MSE = 866.1, and the factor prime type, $F(1,15) = 38.6$, $p < .001$, MSE = 1030.8. Participants responded faster for congruent (500 ms) compared to incongruent (507 ms) primes and they responded faster when the prime fitted the currently relevant S-R rule (499 ms) than when it fitted the currently irrelevant S-R rule (507 ms). The interaction of both factors was not significant ($F(1,15) < 1, p = .39$).

The same ANOVA for error rates showed a significant main effect of prime congruency, $F(1,15) = 4.6$, $p < .05$, MSE = 16.9, as more errors occurred for incongruent (6.5%) compared to congruent primes (5.5%). The other effects were not significant ($p > .15$).

A second analysis was computed to rule out that primes triggered congruency effects only when the prime belonged to the S-R rule of the immediately preceding trial. Like in Experiment 1, the factor repetition vs. switch of the S-R rules (e.g. letter task in $n - 1$ and letter task in n vs. letter task in $n - 1$ and digit task in n) was considered additionally to the factors prime congruency and type of prime. If a prime were only effective when it belonged to the S-R rule that has been performed in the preceding trial then a triple interaction between the factors prime congruency, type of prime, and repetition vs. switch of the S-R rules should occur as congruency effects should be obtained on repetition trials when the prime belongs to the currently (and thereby previously) required S-R rule and on switch trials when the prime belongs to the currently irrelevant (but previously required) S-R rule. Besides the already described effects of prime congruency and type of prime, an ANOVA on RTs revealed a significant main effect of the factor repetition vs. switch of the S-R rule, $F(1,15) = 24.8$, $p < .001$, MSE = 25,965.7. No interaction was significant, $ps > .18$. The same ANOVA on error rates also showed a significant main effect of the factor repetition vs. switch of the S-R rule, $F(1,15) = 12.8$, $p < .01$, MSE = 191.0, and no significant interactions, $ps > .16$. Participants responded faster and with less errors on repetitions of the S-R rule (490 ms and 4.8%) compared to switches of the S-R rule (518 ms and 7.2%).

4.2.2. Prime visibility

The detection rate between the neutral symbol 0 and the occurrence of a prime was $d' = .05$ (the mean hit rate was 63.3%, the mean false alarm rate was 60.4%) and did not deviate from zero, $t(15) = .9$, $p = .38$. The identification rate for the primes was 6.8% and did not significantly differ from chance level of 6.25%, $t(15) = .59$, $p > .56$.

A priming index for the congruency effect independent on prime fit to the relevant or irrelevant S-R rule was computed. A subsequently performed linear regression analysis revealed no significant correlation between d' and the priming index ($r = .047$, $F(1,15) = .03$, $p = .86$). The intercept of the regression was larger than zero (intercept = 1.60, $t(15) = 3.2$, $p < .01$), indicating that a significant priming effect is associated with d' of zero. Thus, the observed priming effect is independent on individual prime visibility.

4.3. Discussion

Experiment 2 shows that subliminal priming occurs in a setting in which participants switch between two different pairs of S-R rules. Furthermore, the size of the priming effect is not reliably influenced by whether the prime fits the currently relevant S-R rule or not. In the former case the effect amounts to 9 ms ($t(15) = 2.6$, $p < .05$) and in the latter case it amounts to 6 ms ($t(15) = 2.5$, $p < .05$). Thus, the second experiment replicates the result of Experiment 1: Subliminal priming can occur according to currently irrelevant S-R rules. Additionally computed analyses reveal that congruency effects are not restricted to cases when the prime belongs to the previously performed S-R rule. This leads us to conclude that it suffices for a prime to be related to a specific response in the overall experimental context. It is not necessary that the prime fits a specific pair of S-R rules that participants pursue in a given trial.

Moreover, there is an overall effect of prime type: Participants responded faster for primes belonging to the currently relevant S-R rule than for primes belonging to the currently irrelevant S-R rule. This suggests that subliminally presented primes may be able not only to activate associated responses but also the stimulus categories to which the responses are assigned, i.e. the required S-R rules (as has been recently suggested by Mattler, 2003 or Reynvoet et al., 2005). We will return to this point in the General discussion.

5. Experiment 3

The third experiment explored whether priming according to different S-R rules can occur in parallel. As in Experiment 1 and 2 participants were to categorize whether a digit is smaller or larger than five or whether a letter is a consonant or vowel. Now prior to each target two primes, a digit <u>and</u> a letter were presented side-by-side. Thus, in each trial a priming effect according to the currently relevant S-R rules and according to the currently irrelevant S-R rules could occur.

5.1. Method

5.1.1. Participants

Sixteen volunteers (aged 19–35) took part each in an individual session of approximately 60 min 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.

5.1.2. Apparatus and stimuli

Apparatus and stimuli were identical to Experiment 2. However, due to an error the monitor was set to 70 Hz for four participants resulting in presentation times of 29 ms for the primes and 72 ms for the masks for these four participants.

5.1.3. Design and procedure

The trial procedure and the design were similar to Experiment 2. In each trial two primes, a letter and a digit were presented simultaneously. The left–right position of the two primes was counter-balanced (letter-digit or digit-letter). There were 256 different trials resulting from each combination of S-R rule (2) × target (4) × letter prime (4) × digit prime (4) × position of primes (2). In each of 8 blocks, 128 of these trials were chosen randomly.

The detection task that was performed after the experiment consisted of 128 trials similar to the experimental trials except that in half of the trials the neutral symbol 00 was presented instead of a prime. Participants were fully informed about the precise structure of the prime stimuli and were asked to indicate which primes were presented by typing the corresponding digits/letters in the order in which they were presented from left to right.

5.2. Results

5.2.1. Congruency effects

Trials with RTs deviating more than 3 standard deviations from the mean RT of each participant (1.5%) as well as trials following an error (6.4%) were excluded. RTs for correct trials and percentages of error (PEs) were averaged for each participant and each combination of the factors prime congruency for the relevant S-R rule and prime congruency for the irrelevant S-R rule.

Table 2 shows mean RTs and error rates depending on prime congruency for the relevant S-R rule and prime congruency for the irrelevant S-R rule. An ANOVA on mean RTs with the within-subject factors prime congruency for the relevant S-R rule and prime congruency for the irrelevant S-R rule revealed that RTs are increased when the prime is incongruent (542 ms) compared to when it is congruent (532 ms) according to the relevant S-R rule, $F(1,15) = 18.4$, $p < .001$, MSE = 1643.4, and when the prime is incongruent (540 ms) compared to when it is congruent (534 ms) according to the irrelevant S-R rule, $F(1,15) = 5.7$, $p < .05$, MSE = 482.3. The interaction of both factors was not significant, $F(1,15) = 2.8$, $p < .12$, MSE = 132.4.

The same ANOVA for error rates showed no significant effects ($p > .14$).

An additional analysis was computed to rule out that primes triggered congruency effects only when they belonged to the S-R rules of the immediately preceding trial. As before the factor repetition vs. switch of the S-R rules (e.g. letter task in $n-1$ and

Table 2
Mean RTs and percentages of errors (*SD* in brackets) depending on prime congruency for the relevant and the irrelevant S-R rule

Congruency for the relevant S-R rule	Congruency according to the irrelevant S-R rule			
	Congruent		Incongruent	
	RT in ms	PE	RT	PE
Congruent	531 (22.0)	6.2 (1.3)	533 (20.7)	6.0 (1.0)
Incongruent	538 (20.0)	7.0 (1.2)	546 (21.1)	7.2 (1.5)

letter task in n vs. letter task in $n-1$ and digit task in n) was considered in addition to the factors prime congruency for the relevant S-R rule and prime congruency for the irrelevant S-R rule. If primes were only effective when they belonged to the S-R rule that has been performed in the preceding trial, then two-way interactions should occur between the factors prime congruency for the relevant S-R rule × repetition vs. switch of the S-R rules and between the factors prime congruency for the irrelevant S-R rule × repetition vs. switch of the S-R rules. Congruency effects for the relevant S-R rule should be restricted to S-R repetition trials, whereas congruency effects for the irrelevant S-R rule should be restricted to S-R switch trials. An ANOVA on RTs revealed that participants responded faster with S-R repetitions (517 ms) than with S-R switches (558 ms), $F(1,15) = 13.7$, $p < .01$, MSE = 53,545.1, and no significant interactions, $ps > .15$. The same ANOVA on error rates showed that errors were less frequent with task repetitions (4.6%) than with task switches (8.6%), $F(1,15) = 11.6$, $p < .01$, MSE = 533.5, and a significant triple interaction, $F(1,15) = 5.9$, $p < .05$, MSE = 22.6. Participants responded faster and with less errors in repetition trials (517 ms and 4.6%) than in switch trials (558 ms and 8.6%). Error rates on repetition trials amounted to 4.8% for incongruent irrelevant and incongruent relevant, 5.0% for congruent irrelevant and incongruent relevant, 4.8% for incongruent irrelevant and congruent relevant, and 3.6% for congruent irrelevant and congruent irrelevant and to 9.4% for incongruent irrelevant and incongruent relevant, 9.0% for congruent irrelevant and incongruent relevant, 7.3% for incongruent irrelevant and congruent relevant, and 8.9% for congruent irrelevant and congruent irrelevant on switch trials. The triple interaction on the error rates will be not further considered as no main effect of congruency was observed on error rates.

5.2.2. Prime visibility

The detection rate between the primes and the neutral symbol (00) was $d' = .16$ (the mean hit rate was 45.7%, the mean false alarm rate was 41.1%) and deviated from zero, $t(15) = 3.2$, $p < .01$. The identification rate for the primes was 1.1% (chance level is 1.56%).

For the regression analysis we chose the larger of the two observed priming effects, i.e. a priming index for the congruency effect according to the relevant S-R rule was calculated. The linear regression analysis revealed no significant correlation between d' and the priming index ($r = .040$, $F(1,15) = .02$, $p = .88$). The intercept of the regression was larger than zero (intercept = 2.01, $t(15) = 3.1$, $p < .01$), indicating that a significant priming effect is associated with d' of zero. Thus, the observed priming effect is not influenced by prime visibility.

5.3. Discussion

Experiment 3 showed that two primes can activate their associated responses literally simultaneously. Like before, the efficacy of primes is independent on the previously performed S-R rules. Hence, both primes were processed according to their appropriate S-R rules. This finding implies that stimulus processing for two different S-R rules works independently of each other.

Table 3
Overview of the mean RTs and the size of the congruency effects (in ms) for Experiment 1–3

	Exp. 1		Exp. 2		Exp. 3	
	Effect referring to		Effect referring to		Effect referring to	
	Relevant S-R rule	Irrelevant S-R rule	Relevant S-R rule	Irrelevant S-R rule	Relevant S-R rule	Irrelevant S-R rule
Congruent prime	–	475	495	505	532	534
Incongruent prime	–	483	504	510	542	540
Congruency effect	–	8	9	6[a]	10	6

[a] Rounded.

6. General discussion

The present study investigated whether the effectiveness of subliminal primes is confined to S-R rules participants are currently performing, or extends to momentarily non-required S-R rules as well. In three experiments we demonstrated that unconscious primes are processed according to currently irrelevant S-R rules to a considerable degree[1] (for an overview of the results see Table 3). These priming effects are independent on the previously performed S-R rule and they occur even when primes for the relevant and irrelevant S-R rules were presented concurrently (Experiment 3). Concerning the mechanisms of subliminal priming, the results contribute to two current debates:

First, in all three experiments letter primes were able to speed up responding to digit primes and vice versa, provided that the primes were assigned to the same response currently required by the target. This result supports response activation accounts of subliminal priming and is in line with previous LRP studies (Dehaene et al., 1998; Eimer & Schlaghecken, 1998): If the target requires the same response as the prime, the prime-induced response activation facilitates target responding. However, if the target requires the alternative response, the prime-induced activation interferes with and thus delays target responding. In contrast, semantic facilitation accounts assume that primes activate semantic categories and thereby speed up semantic analysis of preceding targets (Abrams et al., 2002; Neely, 1991). For

[1] Although, this was not the primary purpose of the present paper we also tested whether the type of S-R mapping had an impact on the priming effect in the irrelevant task. Half of the participants were instructed to press the left response key for digits smaller than five and to press the right response key for digits larger than five, thus their S-R assignment was SNARC compatible (Dehanene, Bossini, & Giraux, 1993). For the other half of participants the S-R mapping was reversed, thus SNARC incompatible. Likewise the mapping for the letter task can be considered compatible when letters early in the alphabet (A, E) are mapped to the left key, and letters later in the alphabet (G, H) are mapped to the right key, rather than with the reversed mapping. We collapsed the data across the three experiments and analyzed whether the priming effect for the irrelevant S-R rule was influenced by SNARC compatibility if the irrelevant S-R rule was the digit task, respectively, whether it was influenced by letter compatibility if the irrelevant S-R rule was the letter task. Compatibility of the S-R mapping had no impact on priming effects neither in RTs nor error rates (all p’s > .14).

example, letter primes would activate categories like “vowel” or “consonant” and digit primes categories like “smaller than five” or “larger than five”. If the target belongs to the same category as the prime, this semantic category is already activated to some degree thereby the semantic processing of the target is facilitated. However, activation of semantic categories alone can hardly explain the present response priming effects across digit and letter stimuli. There is no reason why digit primes should facilitate semantic letter processing and vice versa as digits and letters do not share common categories. Thus, the congruency effects in the present experiments are most likely mediated by response activation, be it that primes literally activate the assigned motor commands or the assigned response codes “left” or “right”.

These considerations do not rule out semantic prime processing. Experiment 2 even provided data in support of semantic prime processing. In this experiment participants responded faster when prime and target were from the same rather than from different stimulus categories (cf. also Reynvoet et al., 2005). However, this effect of categorial concordance did not interact with the response congruency effect. Thus, the primes facilitate processing of targets from the same stimulus category independently of their impact on response preparation. Possibly, primes can activate certain responses without necessarily activating corresponding stimulus categories as well. Future research should clarify to which extent response priming and category priming can occur independently of each other.

Second, response activation accounts have suggested that subliminal primes only “can be used to specify an open parameter of a response, provided that action planning has occurred” (Ansorge et al., 2002, p. 529 cf. also Neumann & Klotz, 1994). Our results complement this view. In Experiment 3, simultaneous priming according to currently relevant <u>and</u> currently irrelevant S-R rules was observed as two prime stimuli were presented concurrently. This finding was replicated in a recent study (Kiesel, Kunde, & Hoffmann, in press) demonstrating that even a single prime stimulus can evoke priming effects according to currently relevant and irrelevant S-R rules as well. Thus, if two different sets of S-R rules exist, the primes automatically activate responses according to both routes implying that the primes can specify response parameters not only according to one current “action plan” but according to several (at least two) “plans” in parallel.

The assumption of parallel response activation according to different S-R routes may explain why Neumann and Klotz (1994, Exp. 4) observed reliable congruency effects only for long cue-to-stimulus-intervals (750 ms and longer). As the two sets of S-R rules in their study were reversed, priming according to the currently relevant and the currently irrelevant set work against each other. Remember that a prime presented on the left side would activate a left response according to the compatible mapping and a right response according to the incompatible mapping. Thus, priming effects according to both mappings cancel out each other if both response activations are of equal strength. However, if participants have enough time to prepare for the currently required S-R rules (and to inhibit the currently irrelevant ones), the interference between the two routes is reduced so that priming effects according to the currently relevant S-R mapping can be observed.

Finally, our results also contribute to the discussion of the origin of the so-called switching costs in the task switching literature (e.g. Allport et al., 1994; Fagot, 1994; Meiran, 1996; Rogers & Monsell, 1995). In our experiments, participants were randomly instructed to either categorize a letter as consonant or vowel or a digit as smaller or larger than five. Accordingly, participants randomly switched between both tasks (for similar settings in the task switching paradigm see Allport et al., 1994; Hübner, Dreisbach, Haider, & Kluwe, 2003; Hübner, Futterer, & Steinhauser, 2001; Kiesel, Wendt, & Peters, in press; Koch, 2003; Rogers & Monsell, 1995; Sohn & Carlson, 2000). As in all other task switching experiments, we observed significant switch costs, i.e. RTs and error rates increased in trials in which the task switched in comparison to trials in which the preceding task repeated. However, primes from the currently irrelevant stimulus categories produced nearly the same congruency effects as primes from the currently relevant stimulus categories. Moreover, the sizes of the priming effects were independent of whether the S-R rules (i.e. task) of the previous trial repeated or switched. As relevant and irrelevant primes likewise have access to the required responses, both task sets (S-R rules) seem to be kept active in parallel almost irrespective on which S-R rule is currently required. This contradicts the idea of a literal task "switch" operation that controls the activity of task sets in an all-or-none manner (cf. the railway metaphor in Rogers & Monsell, 1995) and it casts into doubt the assumption that switch costs reflect the need to 're-activate' the currently appropriate S-R mapping[2] (for similar considerations see Hoffmann, Kiesel, & Sebald, 2003).

Our findings are rather consistent with the notion that actors can retain at least two task sets simultaneously, modulating only the strength of their activation in order to meet current requirements. Accordingly, the activation of the relevant task exceeds that of the irrelevant task to an extent that allows accurate performance, but without hampering switching back to the irrelevant task set too much (like proposed by Meiran, 2000). Several observations are in line with this notion. For example, Gopher, Armony, and Greenshpan (2000) have shown that participants can already prepare for a switch that has to be carried out some trials later. Likewise Hübner, Kluwe, Luna-Rodriguez, and Peters (2004) reported that the size of target congruency effects do not increase when participants invalidly prepare the currently irrelevant task. This suggests that even without invalid task preparation the irrelevant task set remains activated thereby producing considerable target congruency effects.

To conclude, we have shown that unconscious stimuli impact behavior according to at least two S-R rules in parallel. This observation extends current knowledge on the capabilities of unconscious priming. Moreover, the impact of subliminal primes might turn out as a useful method to study the maintenance of S-R assignments. Experiments that explore the conditions of such maintenance in more detail are on the way.

[2] We are grateful to an anonymous reviewer for pointing out this conclusion.

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