

## Incidental Learning of S-R Contingencies in the Masked Prime Task

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Subliminal motor priming effects in the masked prime paradigm can only be obtained when primes are part of the task set. In 2 experiments, the authors investigated whether the relevant task set feature needs to be explicitly instructed or could be extracted automatically in an incidental learning paradigm. Primes and targets were symmetrical arrows, with target color, not shape, the response-relevant feature. Shape and color covaried for targets (e.g., <> always blue, >< always green), whereas primes were always black. Over time, a negative compatibility effect (NCE; response benefits when prime and target had different shapes) developed, indicating that primes affected the motor system. When target shape and color varied independently (control condition), no NCE occurred, in line with the assumption that the NCE reflects task set-dependent motor processes, not perceptual interactions.

*Keywords:* low-level motor control, masked priming, incidental learning, configural learning, negative compatibility effect

Most people would regard the possibility that their behavior could be influenced by subliminal stimuli as worrying. If stimuli that have not been consciously perceived could affect their actions, then this would seem to suggest that individuals are at the mercy of undetectable—and hence uncontrollable—external forces. Clearly, this concept stands in opposition to individuals' intuitive notion that the decisions determining their actions are made by them—that they are voluntary, free, and under their own control. Yet increasing evidence suggests that such nonconscious influences do in fact exist. Subliminal stimuli have been found to bias subjectively free semantic and affective processing (see, e.g., Kihlstrom, 1999) and motor response choices (e.g., Klapp & Hinkley, 2002; Schlaghecken & Eimer, 2004).

However, at least in these latter cases, it has also been demonstrated that the impact of subliminal information on behavior depends on the currently active task set, that is, on the set of stimulus–response (S-R) mappings imposed by the task instructions and applied by the participant (e.g., Ansorge, Heumann, & Scharlau, 2002; Eimer & Schlaghecken, 1998; Klapp & Haas, 2005; Klapp & Hinkley, 2002; Kunde, Kiesel, & Hoffmann, 2003; Neumann & Klotz, 1994; Schlaghecken & Eimer, 2004). Thus, although the processes triggered by subliminal stimuli are low level and automatic in the sense of being outside voluntary control, they nevertheless depend on high-level intentional states, making it unlikely that subliminal stimuli could control people's actions independently of, or even contrary to, their intentions.

Although this is a comforting notion, the question remains of how such intentions are formed in the first place. In most psychological experiments—including those on subliminally biased re-

sponse choices—a specific intention is operationalized as a specific task instruction given to the participant (e.g., “Make a left-hand response when a left-pointing arrow appears and a right-hand response when a right-pointing arrow appears”). However, most of individuals' intentions are not formed in this way but result from more direct interactions with their environment (e.g., people would not normally reach for a glass of water because they are told to do so but because they are thirsty and have learned from experience that drinking water will quench their thirst).

The present study investigated whether such incidental learning can result in intentional states that are equivalent to explicitly instructed intentions in the sense that they will cause a similar susceptibility to subliminal influences. A modified version of the masked prime paradigm (Eimer & Schlaghecken, 1998; Schlaghecken & Eimer, 1997) was employed to test (a) whether masked prime stimuli would activate their corresponding motor response even under conditions in which the appropriate S-R mapping had not been explicitly instructed and (b) whether any such low-level motor processes would exhibit the same time course of activation followed by self-inhibition usually observed in this paradigm.

In the standard masked prime paradigm, responses are assigned to simple visual stimuli (e.g., a left-hand response to left-pointing arrows and a right-hand response to right-pointing arrows). On each trial, these target arrows are preceded by backward-masked prime stimuli. On compatible trials, the prime is an arrow pointing in the same direction as the subsequent target. On incompatible trials, the prime is an arrow pointing in the opposite direction to the subsequent target. On neutral trials, the prime is a stimulus that never occurs as a target and hence has no response assignment (e.g., a nonarrow stimulus like a plus or equals sign). Because the primes are presented very briefly (usually for only 17 ms) and are immediately followed by a masking stimulus, they remain near or below the threshold of conscious perception: Participants not only report that they have not been aware of any prime stimuli, but they also usually fail to perform with better-than-chance accuracy in prime identification tasks (Eimer & Schlaghecken, 1998, 2002;

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Schlaghecken & Eimer, 1997, 2004). However, behavioral, electrophysiological, and hemodynamic evidence indicates that these subliminal primes nevertheless trigger an activation of their assigned motor response, reflected in corresponding priming effects on reaction times (RTs) and error rates (Aron et al., 2003; Damian, 2001; Dehaene et al., 1998; Eimer, 1999; Eimer & Schlaghecken, 1998, 2001, 2002; Eimer, Schubö, & Schlaghecken, 2002; Klapp, 2005; Klapp & Haas, 2005; Klapp & Hinkley, 2002; Naccache & Dehaene, 2001; Schlaghecken & Eimer, 1997, 2000, 2001, 2002).

The direction of these priming effects depends on the stimulus onset asynchronies among primes, masks, and targets (for an overview, see Eimer & Schlaghecken, 2003). When the target appears simultaneously with the mask (0-ms stimulus onset asynchrony), positive compatibility effects (PCEs) are obtained, with behavioral benefits on compatible trials and costs on incompatible trials, relative to neutral trials. This suggests that the prime activates its assigned response and that this increased unilateral activation level inhibits the opposite response. However, when the target follows mask onset with stimulus onset asynchronies of 100 ms or more, this pattern reverses and turns into negative compatibility effects (NCEs), with behavioral benefits on incompatible trials and costs on compatible trials. This has been taken as evidence that the preactivated (primed) motor response will quickly self-inhibit if it is no longer supported by sensory evidence, causing a corresponding disinhibition of the alternative response channel (Bowman, Schlaghecken, & Eimer, 2006; Eimer & Schlaghecken, 1998, 2003; Schlaghecken & Eimer, 2002, 2006).

It is important to reiterate, though, that these subliminal priming effects are obtained only if primes are part of the current task set. For example, left- or right-pointing arrow primes have been found to trigger PCEs and NCEs only when at least some of the targets are left- or right-pointing arrows as well. If responses are assigned exclusively to a different type of target (e.g., to letter stimuli), arrow primes will not elicit any priming effects (Eimer & Schlaghecken, 1998, Experiment 1b). Even more striking are results from free-choice experiments (Klapp & Haas, 2005; Klapp & Hinkley, 2002; Schlaghecken & Eimer, 2004). Participants again had to respond to targets preceded by masked arrow primes. On instructed trials, arrow targets required a left or right response. On additional free-choice trials, a nondirectional target indicated that participants were free to choose either response. Masked arrow primes were found to systematically affect the free choice between response alternatives—but only as long as free-choice trials were mixed with instructed (arrow) trials. In pure free-choice blocks, in which no instructed trials were presented, masked arrow primes failed to affect free-choice performance. Of note, this was true even for free-choice blocks that immediately followed mixed blocks: No carryover effects from the previously relevant arrows were observed when participants were not explicitly instructed to respond to arrows (Schlaghecken & Eimer, 2004). Corresponding results have been obtained in a number of different motor priming tasks employing the metacontrast paradigm (e.g., Ansorge et al., 2002; Klotz & Neumann, 1999; Kunde et al., 2003), suggesting that the instruction dependency of subliminal motor priming effects is not paradigm specific but reflects a fundamental feature of the underlying perceptuo-motor control processes.

The finding that masked priming effects will be obtained only when primes are part of the task set has been interpreted in terms of direct perceptuo-motor links (e.g., Ansorge et al., 2002; Klotz & Neumann, 1999; Neumann & Klotz, 1994). According to this

account, the role of the task set is to adjust the configuration of the motor system in accordance with current task requirements, thus making it particularly susceptible to certain inputs and particularly likely to execute certain actions. An additional finding has been that masked priming effects will be obtained only when the task set is actively reinforced (i.e., when participants are explicitly instructed to respond to the relevant stimuli and when these stimuli are presented as targets on at least some of the trials; Schlaghecken & Eimer, 2004). This strongly suggests that the task set-dependent configuration is nonstable and short lived and that it is updated regularly.

It is unclear, however, whether this process requires explicit instructions and conscious intentions, as suggested by the free-choice results. Alternatively, it might be possible that task sets can be established and updated or maintained on the basis of potentially response-relevant stimulus contingencies in the environment, even if these are not part of the participant's conscious intentions. The aim of the present study was to investigate this issue by employing the masked prime paradigm in an incidental learning situation.

## Experiment 1

Two different nondirectional arrow stimuli were presented in two different colors, with target color, not target shape, as the response-relevant stimulus feature. However, target shape and color covaried (e.g., <> always blue, >< always green), although this was not mentioned to the participant. In contrast to the targets, masked primes were always black, that is, they lacked the response-relevant color feature. Targets were presented 150 ms after prime offset–mask onset. The question of interest was whether NCEs (behavioral costs on trials in which prime and target shape matched compared with trials in which they mismatched) would be observed under these conditions. If low-level perceptuo-motor control processes can operate only within the limits of an explicitly instructed and intentionally activated task set, then no priming effects should be observed. If, however, these processes adapt flexibly to potentially response-relevant stimulus contingencies, normal NCEs should be obtained.

It is possible, of course, that participants become aware of the color–shape contingency very quickly and then consciously use this knowledge to establish a new self-instructed task set. In order to test for this possibility, we assessed the participants' knowledge about the color–shape relationship both directly and indirectly. The direct measure of explicit, verbally accessible knowledge was participants' verbal responses on an explicit-knowledge questionnaire administered at the end of the experiment. The indirect measure was behavioral performance in a test block, administered at the end of each experimental half, where target shape and color varied independently (i.e., each target randomly appeared in either color). If participants had acquired knowledge about the color–shape relationship, their performance should be impaired by the presentation of reversed color–shape pairings. It should be noted, however, that the extent of participants' explicit knowledge was only of secondary interest here. Thus, for the purpose of the present study, we adopted the following strategy: All learning of color–shape contingencies was assumed to be incidental, as participants were not explicitly instructed that such contingencies existed. Knowledge of the color–shape contingencies was said to

be explicit when participants were able to produce an appropriate verbal description of these contingencies (i.e., a description that could have served as a verbal instruction, e.g., “Most of the time, the inward-pointing arrows were blue, and the outward-pointing arrows were green”). When they were not able to produce such a description, participants’ knowledge was classified as implicit.

### Method

#### Participants

Sixty volunteers (15 men), aged 18–39 years (mean age: 20.6 years), participated in the experiment for either course credit or payment of £5 (\$9.89). According to self-report, all but 3 participants were right-handed and all had normal or corrected-to-normal vision. Participants were assigned to one of two experimental groups: consistent mapping (CM) or control. Five participants were excluded from the analysis because of excessively high error rates and/or long RTs (more than two standard deviations above the mean), leaving 30 participants in the CM group and 25 in the control group.

#### Stimuli and Apparatus

Bidirectional arrows (<> and ><) and a quartered rectangle constructed from discontinuous lines (box stimulus, ) served as prime and target stimuli, each subtending a visual angle of approximately  $0.9^\circ \times 0.4^\circ$ . Masks were constructed from a  $9 \times 9$  matrix, randomly filled with overlapping horizontal, vertical, and oblique lines of different length, resulting in a roughly rectangular array of approximately  $2.2^\circ \times 1.5^\circ$ . A new random mask was constructed on each trial. Targets were presented in either blue or green; primes and masks were presented in black. All stimuli were presented on a white background in the center of a 17-in. (43.2-cm) computer screen.

#### Procedure

Participants were seated in a dimly lit, sound-attenuated chamber in front of a computer screen (viewing distance = 1 m), with response buttons under their left and right index fingers. The experiment comprised four tasks for the CM group (priming, test, prime detection, and explicitness questionnaire) and two tasks for the control group (priming and prime detection).

In priming and test blocks, each trial began with a prime, presented for 17 ms. This was immediately followed by a mask (presented for 100 ms), followed by a blank screen (50 ms). Next, a target was displayed for 100 ms. The intertrial interval was 1,460 ms (see Figure 1). Arrow stimuli were presented as targets on 90% of the trials. On the remaining 10%, box stimuli were presented, in order to emphasize color over shape. Data from these catch trials were not analyzed. Participants were instructed to maintain central eye fixation and to respond as quickly and as accurately as possible to the color of the targets. In each group, half of the participants responded with a left keypress to blue stimuli and with a right keypress to green stimuli; for the other half, this assignment was reversed. In order to further emphasize the importance of color over shape (without explicitly misleading participants in the CM group by informing them that there was no color–shape relationship), we began all blocks except for the prime detection task (see

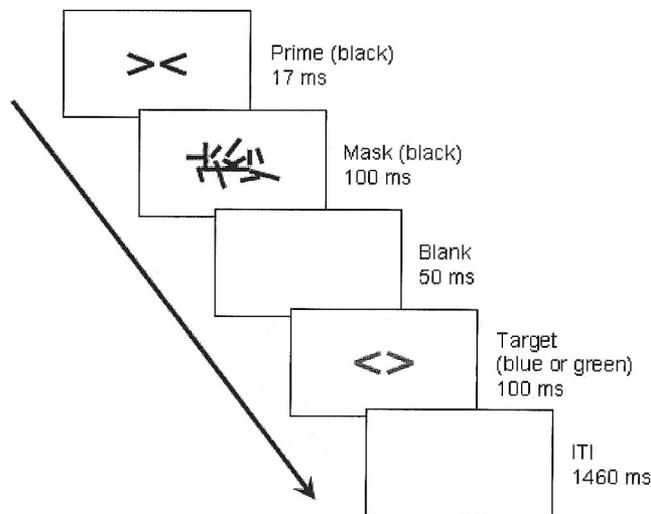


Figure 1. Illustration of the sequence of events during a trial in the priming and test blocks. ITI = intertrial interval.

below) with an instruction screen that displayed all shapes in both colors (see Figure 2).

In priming blocks, all three types of prime stimuli (box, inward-pointing arrows, and outward-pointing arrows) were employed. Trials were termed *compatible* when arrow prime and arrow target had the same shape, *incompatible* when they had different shapes, and *neutral* when the prime was the box stimulus. For the CM group, color and shape of arrow targets covaried (e.g., <> always blue, >< always green, or vice versa), whereas for the control group, color and shape varied independently (i.e., all color–shape combinations were equiprobable). Left and right responses and compatible, incompatible, and neutral trials were equiprobable and randomized within each block. The experiment consisted of two halves, each beginning with 80 trials of practice followed by six priming blocks of 60 trials each.

Participants in the CM group performed a further test block of 80 trials at the end of each experimental half. These blocks were identical to the priming blocks except that (a) only box stimuli served as primes and (b) target color and shape did not covary (i.e., all color–shape combinations were equiprobable).

At the end of the experiment, participants performed a 90-trial prime detection task. On 50% of the trials, primes were presented for 17, 33 or 50 ms, randomly and with equal probability. On the remaining 50%, no prime preceded the mask. No targets were presented after the mask.<sup>1</sup> Participants were fully informed about these facts. They were instructed to indicate with a right or left keypress whether a prime was present, and they were strongly encouraged to “just guess” when they were unable to make an informed decision on any given trial.

<sup>1</sup> It has been found previously that presenting the complete stimulus sequence of prime, mask, and target in a prime identification or detection task makes it virtually impossible for the participants to follow task instructions in a meaningful way (e.g., Schlaghecken & Eimer, 1997). According to their subjective reports, participants become confused by the target and feel unable to even attempt to respond to a prime they do not consciously perceive. Presenting a target in a prime identification task thus is likely to artificially reduce performance levels.

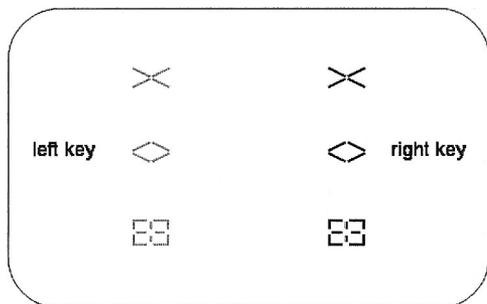


Figure 2. Instruction screen as presented to the participant at the beginning of each block. All possible target shapes were presented in both colors (black = blue; gray = green), irrespective of the participant's actual color–shape mapping. However, each color was positioned so as to correspond to the correct mapping (e.g., if blue stimuli required a right-hand response, then all blue stimuli were presented on the right side of the screen).

Finally, participants in the CM group completed a questionnaire to estimate the extent of their explicit knowledge of the color–shape relationship. The full set of possible target stimuli were displayed on the computer screen, similar to the instruction screens encountered at the beginning of each block but without the instructions “left key” and “right key.” The experimenter then asked three progressively more explicit questions about the display (Question 1: “Did you notice anything unusual about these stimuli during the experiment?” Question 2: “Have you seen some of these stimuli less often than others during the experiment?” Question 3: “Have you seen some of these colored arrows less often than others during the experiment?”). If asked for clarification, the experimenter would rephrase the question but without giving any additional hints (e.g., Question 2 might be rephrased as “Do you think that some of these stimuli occurred quite a lot, and others very rarely or not at all?”). Responses were recorded manually by the experimenter. The questioning was terminated when either the participant gave a full and correct answer or after Question 3 had been answered. Participants in the control group did not perform the test blocks and did not complete the explicitness questionnaire.

### Data Analysis

For the analysis of prime detection performance, we calculated hit rates on prime-present trials (separately for each prime duration) and false alarm rates on prime-absent trials separately for each experimental group. Results were analyzed using a repeated-measures analysis of variance (ANOVA), with the within-subject variable duration (50, 33, and 17 ms) and the between-subjects variable experimental group (CM, control), and with a subsequent ANOVA, with the within-subject variable prime presence (17-ms prime vs. no prime) and the between-subjects variable experimental group.

Participants were classified as having explicit (E) or implicit (I) knowledge as follows: Participants who gave a correct response without direct prompting were classified as E, participants who gave only partially correct responses or who made a correct response only after direct prompting (Question 3) were classed as

I+, and participants who failed to give a correct report on any question were classified as I–.

For priming and test blocks, only arrow target trials were analyzed (catch trials were not analyzed), and all trials with missing responses or with RTs of more than 1,000 ms or less than 200 ms were discarded (1.4% of all trials). Mean RTs on correct trials and error rates were calculated separately for compatible, neutral, and incompatible trials in the priming blocks, and for normal and reversed color–shape mapping in the test blocks. In addition, overall correct RT and error rate were calculated for all arrow trials (irrespective of compatibility) in the priming block immediately preceding each test block, in order to directly compare priming block and test block performance.

The extent to which color–shape contingencies affected participants' overt behavior was assessed in two steps: (a) An ANOVA, with the within-subject variables block (test block, priming block) and half (first experimental half, second experimental half), was conducted comparing RTs on normal-mapping trials of the test blocks with RTs in the immediately preceding priming blocks (a corresponding analysis was conducted for error rates). (b) Within test blocks, an ANOVA, with the within-subject variables trial (normal mapping, reversed mapping) and half, was conducted for RTs and error rates.

Priming effects were analyzed by comparing behavioral performance on compatible, incompatible, and neutral trials and subsequently by directly comparing behavioral performance on compatible and incompatible trials. Within each experimental half, priming blocks were organized into three successive parts containing two blocks each. Analyses of RTs and error rates were conducted using ANOVAs, with the within-subject variables half (first and second experimental half), part (Part 1, Part 2, Part 3 within each half), and compatibility (compatible, incompatible), and the between-subjects variable experimental group. Greenhouse–Geisser corrections of the degrees of freedom were performed where appropriate, and corrected  $p$  values are reported.

## Results

### Prime Detection Performance

As depicted in Figure 3, prime detection performance deteriorated with decreasing prime duration,  $F(2, 106) = 72.68$ ,  $MSE = 457.02$ ,  $p < .001$  (two-tailed), but hit rate for 17-ms primes was still significantly higher than false alarm rate,  $F(1, 53) = 36.36$ ,  $MSE = 150.56$ ,  $p < .001$  (two-tailed). Neither of these results differed between experimental groups (all  $F$ s  $< 1$ ).

### Color–Shape Knowledge in the CM Group

*Direct measure.* Six participants were classified as E, 14 as I+, and 9 as I–. Questionnaire data from 1 participant were missing.

*Indirect measures—between blocks.* As can be seen from Figure 4, RTs were longer in the first than in the second experimental half,  $F(1, 26) = 8.48$ ,  $MSE = 307.34$ ,  $p = .007$  (two-tailed), and longer on normal-mapping trials in test blocks than on arrow trials in the preceding priming blocks,  $F(1, 26) = 13.88$ ,  $MSE = 325.14$ ,  $p = .001$  (two-tailed). This latter effect was absent only for the I+ group in the first experimental half, giving rise to a marginally

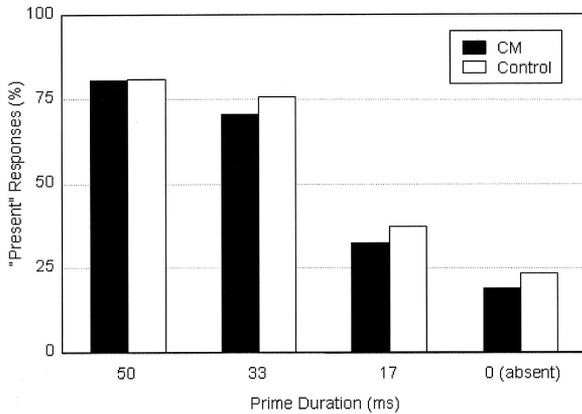


Figure 3. Forced-choice prime detection performance in Experiment 1, separately for the consistent mapping (CM) group (black) and the control group (white).

significant three-way interaction of Group  $\times$  Half  $\times$  Block,  $F(2, 26) = 2.56$ ,  $MSE = 282.00$ ,  $p = .097$  (two-tailed). No other main effects or interactions were observed (all  $F_s < 1.8$ , all  $p_s > .18$ ). Error rates did not show any between-blocks learning effects or differences among explicitness groups (all  $F_s < 1.5$ , all  $p_s > .25$ , two-tailed).

*Indirect measures—within blocks.* Error rates in the test blocks were higher in Group E than in the other two groups,  $F(1, 26) =$

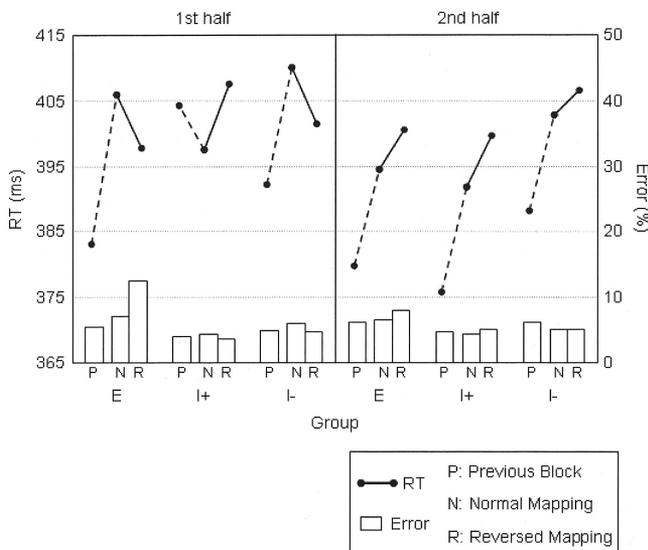


Figure 4. Indirect learning measures in the consistent mapping group of Experiment 1, separately for each experimental half. Depicted are mean reaction times (RTs; lines) and error rates (bars) on all arrow trials (collapsed across compatibility conditions) in the priming block immediately preceding the test block (P), and mean RTs and error rates on normal-mapping (N) and reversed-mapping (R) arrow trials in the test blocks, separately for each explicitness group (E = participants who gave a correct response without direct prompting; I+ = participants who gave only partially correct responses or made a correct response only after direct prompting; I- = participants who failed to give a correct report on any question).

4.42,  $MSE = 33.82$ ,  $p = .022$  (two-tailed). Overall, RTs tended to be longer on reversed mapping trials than on normal-mapping trials for the I+ group, whereas the other two groups tended to show the opposite pattern,  $F(1, 26) = 3.15$ ,  $MSE = 135.57$ ,  $p = .060$  (two-tailed). There was no other effect on either RTs or error rates (all  $F_s < 2.5$ , all  $p_s > .11$ ). However, subsequent analysis, conducted on data from the second experimental half only, confirmed that RTs were longer for reverse-mapping than for normal-mapping trials,  $F(1, 26) = 4.49$ ,  $MSE = 100.73$ ,  $p = .044$  (two-tailed), regardless of explicitness group ( $F < 1$ ). No main effects or interactions were obtained for second-half error rates (all  $F_s < 1.8$ , all  $p_s > .19$ ).

*Masked Prime Task Performance*

Preliminary analyses revealed that performance on neutral trials showed virtually identical time courses for the two groups, whereas differences were apparent between compatible and incompatible trials. Because these were the only conditions of interest (i.e., the only conditions expected to be influenced by the experimental manipulation), subsequent analyses were restricted to compatible and incompatible trials.

Mean RTs and error rates for each group and priming condition are presented in Figure 5. There were virtually no compatibility effects in the first experimental half for either group. In the second half, however, NCEs developed in the CM group, whereas no systematic compatibility effects were apparent for the control group. For RTs, this pattern was supported by a significant Compatibility  $\times$  Part  $\times$  Group interaction,  $F(2, 106) = 3.09$ ,  $MSE = 129.71$ ,  $p = .049$  (two-tailed), which was accompanied by a significant Compatibility  $\times$  Experimental Half interaction,  $F(2, 106) = 5.87$ ,  $MSE = 118.84$ ,  $p = .019$  (two-tailed). For error rates,

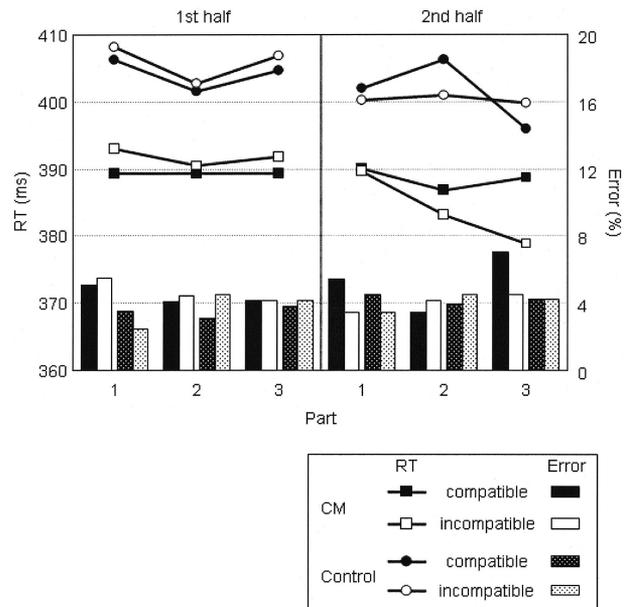


Figure 5. Mean reaction times (RTs; lines) and error rates (bars) on compatible (black) and incompatible (white) arrow trials for each half and part of Experiment 1, separately for the consistent mapping (CM) group (squares, plain bars) and the control group (circles, dotted bars).

the Compatibility  $\times$  Part interaction,  $F(2, 106) = 2.85, p = .062$  (two-tailed), and the Half  $\times$  Part  $\times$  Experimental Group interaction,  $F(2, 106) = 2.82, p = .064$  (two-tailed), almost reached significance. No other main effects or interactions were significant (all  $F$ s  $< 2.8$ , all  $p$ s  $> .10$ , two-tailed). Two subsequent sets of ANOVAs were performed—one on each group—on data from the last part of the second experimental half (see Figure 6). This analysis confirmed that at the end of the experiment, significant NCEs existed for RTs,  $F(1, 26) = 8.19, MSE = 135.09, p = .008$  (two-tailed), and error rates,  $F(1, 26) = 4.46, MSE = 10.04, p = .044$  (two-tailed), in the CM group, which did not differ among explicitness groups (both  $F$ s  $< 1.2$ , both  $p$ s  $> .3$ , two-tailed). No such effects were observed for the control group (both  $F$ s  $< 1.4$ , both  $p$ s  $> .25$ , two-tailed).

### Discussion

The present experiment demonstrates that in a masked prime task, motor priming effects triggered by the shape of subliminally presented prime stimuli can be observed even when stimulus shape is not part of the explicitly instructed task set but only covaries with the task-relevant stimulus feature. Participants responded to the color of target stimuli with a left or right keypress. For half of the participants (CM group), target color and target shape covaried on 90% of the trials. Participants were not alerted to this fact, and their verbal responses in a subsequent explicitness questionnaire indicated that most of them had not paid much conscious attention to the color–shape contingency. Nevertheless, motor priming effects typical for the masked prime paradigm (NCEs: faster and more accurate responses when prime and target shape mismatched than when they matched) developed by the end of the experiment. No such effects were found when target shape and color did not covary (control group).

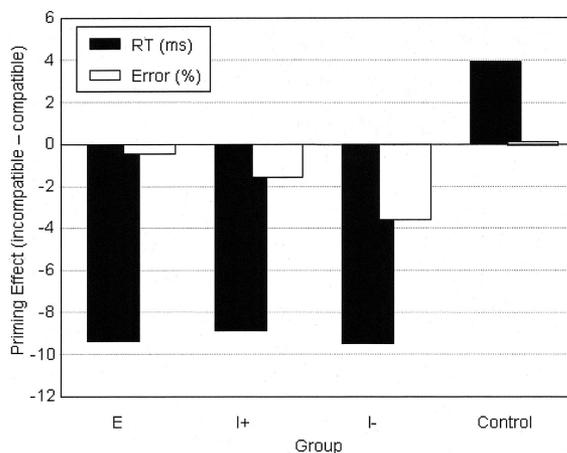


Figure 6. Experiment 1: Priming effects (incompatible minus compatible) on reaction times (RTs in ms; black bars) and error rates (in %; white bars) in Part 3 of the second experimental half, separately for each explicitness group of the consistent mapping group (E = participants who gave a correct response without direct prompting; I+ = participants who gave only partially correct responses or made a correct response only after direct prompting; I- = participants who failed to give a correct report on any question), and for the control group.

To the best of our knowledge, this is the first time that these two major areas of research into nonintentional processing—incidental learning and subliminal motor priming—have been studied in conjunction. Earlier findings demonstrated that in order for subliminal stimuli to elicit motor priming effects, these stimuli need to be part of the currently active task set: Only if participants are already prepared to give a particular response to a particular stimulus will it be possible for this stimulus to subliminally affect overt behavior (Eimer & Schlaghecken, 1998; Klapp & Haas, 2005; Klapp & Hinkley, 2002; Schlaghecken & Eimer, 2004). The present results extend these findings by demonstrating that for priming effects to occur, the task set does not need to be established via explicit instruction. Rather, it is sufficient that over time, participants can extract the relevant feature from the stimulus contingencies present in the experimental environment.

Explicitness scores indicated large differences in the amount of conscious, verbalizable knowledge acquired by the participants, ranging from more or less completely explicit, verbalizable knowledge to a complete inability to express any explicit knowledge about the color–shape contingency at all. Nevertheless, significant indirect learning effects were observed in the overall increase of RTs from priming to test blocks and in the slowing of responses on reverse-mapping trials relative to normal-mapping trials in the final test block. It is interesting to note that these effects did not vary with the amount of direct, explicitly reported knowledge, suggesting that the direct and indirect measures employed here reflect different aspects of learning.

However, given the simplicity and consistency of the color–shape mapping, it seems surprising that only a few participants were able to express explicit knowledge and that the indirect learning effects were relatively small. Furthermore, although the size of the NCEs in the last part of the experiment (9-ms RT difference, 2.5% error difference) was comparable with NCEs reported in some earlier studies (e.g., Schlaghecken & Eimer, 2004; Schlaghecken & Sisman, 2006), it was considerably smaller than in most (e.g., Schlaghecken, Bowman, & Eimer, 2006; Schlaghecken & Eimer, 2002; Schlaghecken & Maylor, 2005). It is thus desirable to replicate and to extend these results, which was the aim of Experiment 2.

### Experiment 2

In this experiment, a similar design to Experiment 1 was employed, with a few important modifications. First, in Experiment 1, the number of catch trials (trials in which the target was a colored box) was insufficient to test whether primes would trigger compatibility effects when the target was a box rather than a bidirectional arrow stimulus. If the assumption is correct that priming effects reflect low-level perceptuo-motor control processes triggered by the prime and its subsequent disappearance, then these effects should be the same for all target types. Thus, in Experiment 2, the percentage of catch trials was increased from 10% to 25% in order to obtain sufficient numbers to test for compatibility effects (for the same reason, neutral trials—which are of no interest in the present context—were omitted, and experimental blocks were grouped into three, not six, successive parts for data analysis).

Second, in order to address the concern that, in Experiment 1, even participants with low explicitness scores might have had at least some explicit, verbally accessible knowledge of the color–

shape mapping, we simplified the explicitness questionnaire and used an additional forced-choice test. Third, the test block at the end of the first experimental half was omitted to avoid participants “unlearning” any potential knowledge about the color–shape mapping. Finally, no control group was tested as there was no reason to believe that increasing the number of catch trials would alter the fact that no priming effects were elicited when there was no consistent color–shape mapping.

### Method

#### Participants

Twenty-two volunteers (13 men), aged 19–28 years (mean age: 23.4 years), participated in the experiment for either course credit or payment of £5. According to self-report, all but 2 participants were right-handed and all had normal or corrected-to-normal vision. Two participants were excluded from the analysis, 1 because of excessively high error rates (more than two standard deviations above the mean) and 1 because of near-perfect prime perception (100% correct detection of 17-ms primes, 2.2% false alarm rate).

#### Stimuli and Apparatus

These were identical to Experiment 1.

#### Procedure

The procedure was similar to Experiment 1, with the following exceptions: (a) There was only a CM group. (b) Catch trials (colored box stimuli) were presented on 25% of all trials. (c) No neutral trials were presented. (d) Only one test block (with randomized color–shape mapping) was presented, after all priming blocks had been completed. (e) The postexperiment assessment of explicit knowledge was changed in a way that was deemed to be more suitable to differentiate between E and I learners. Participants were not shown the instruction screen (which always displayed all shapes in all colors). First, they were asked whether they had noticed any difference between the last (test) block and the preceding blocks (spontaneous report). Next, they were asked whether they had noticed any difference in the colored arrow stimuli between the last (test) block and the preceding blocks (prompted report). Finally, they were shown both types of arrow stimuli in a neutral color (black) and were asked to indicate which shape had usually appeared in which color (forced-choice report). Participants were required to make a guess if they did not feel they knew the answer to the last question.

#### Data Analysis

Experimental blocks were grouped into three successive parts of four blocks each. Arrow target and box target trials in each part and in the final test block were analyzed, and trials with RTs of more than 700 ms or less than 250 ms were discarded (3% of all trials). Participants’ level of explicit knowledge was quantified as follows: Participants who correctly reported the color–shape contingencies in answer to Questions 1 or 2 were labeled *E*. Participants who failed to report the color–shape mapping both spontaneously and after prompting but correctly guessed the mapping in the forced-choice mapping task were labeled *I+*. Participants who

failed to report the color–shape mapping and also failed to correctly guess the mapping in the forced-choice mapping task were labeled *I-*.

### Results

#### Prime Detection Performance

As in Experiment 1, prime detection performance deteriorated with decreasing prime duration,  $F(2, 38) = 26.89$ ,  $MSE = 333.43$ ,  $p < .001$  (two-tailed). However, the 17-ms hit rate was higher than the false alarm rate,  $t(19) = 2.12$ ,  $p = .047$  (two-tailed; see Figure 7).

#### Knowledge of Color–Shape Mapping

*Direct measure.* Six participants displayed explicit knowledge of the color–shape mapping (Group E). Of the remaining 14 participants, 10 correctly guessed the mapping and were classed as *I+*, whereas 4 failed to correctly guess the mapping and were classed as *I-*.

*Indirect measures.* As Figure 8 suggests, RTs tended to be longer in the test block than in the preceding priming block,  $F(1, 17) = 4.02$ ,  $MSE = 497.48$ ,  $p = .031$  (one-tailed). However, similar to Experiment 1, the RT difference between normal and reversed mapping within the test block was not significant ( $F < 1$ ). In contrast, the error difference between mappings approached significance,  $F(1, 17) = 2.59$ ,  $MSE = 16.81$ ,  $p = .063$  (one-tailed), whereas the error difference between blocks did not ( $F < 1$ ). Only the between-blocks error effect differed among groups,  $F(2, 17) = 4.12$ ,  $MSE = 14.28$ ,  $p = .035$ , with Group *I+* producing more errors in the test than in the preceding prime block, and Groups E and *I-* showing the opposite pattern. The remaining learning effects did not differ significantly among groups (all  $F$ s  $< 2.2$ , all  $p$ s  $> .14$ , two-tailed).

#### Masked Prime Task Performance

Mean RTs and error rates for each part and target are presented in Figure 9; priming effects on RTs and error rates for each group (Part 3 only) are presented in Figure 10. Overall, error rates tended to be higher on compatible trials (3.3%) than

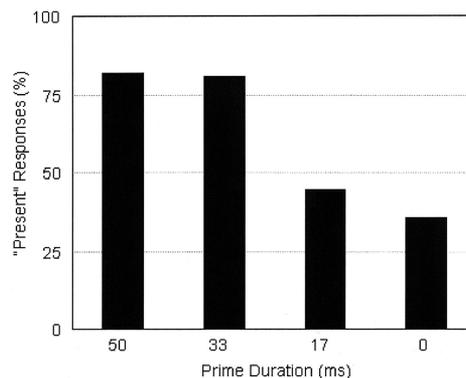


Figure 7. Forced-choice prime detection performance in Experiment 2.

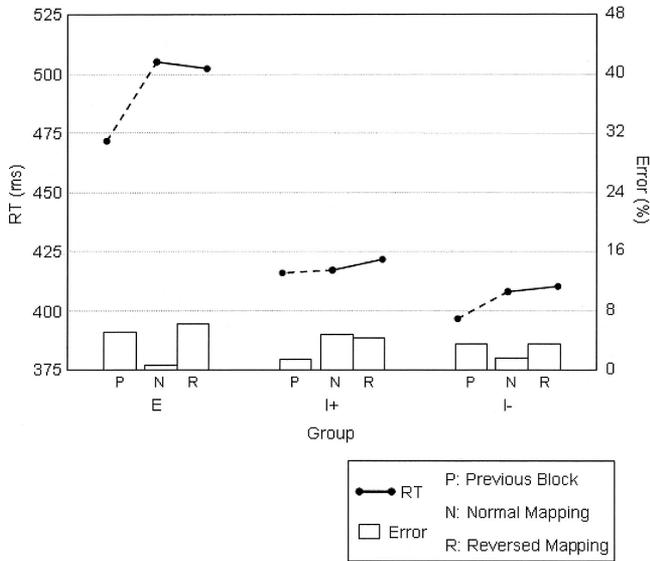


Figure 8. Indirect learning measures in Experiment 2. Depicted are mean reaction times (RTs; lines) and error rates (bars) on all arrow trials (collapsed across compatibility conditions) in the priming block immediately previous to the test block (P), and mean RTs and error rates on normal-mapping (N) and reversed-mapping (R) arrow trials in the test block, separately for each explicitness group (E = participants who gave a correct verbal report; I+ = participants who failed to give a correct verbal report but guessed correctly in the forced-choice task; I- = participants who failed to give a correct verbal report and guessed incorrectly in the forced-choice task).

on incompatible trials (2.6%),  $F(1, 17) = 3.15$ ,  $MSE = 7.86$ ,  $p = .047$  (one-tailed). As in the previous experiment, there was no other main effect or interaction for error rates (all  $F_s < 3$ , all  $p_s > .1$ , two-tailed).

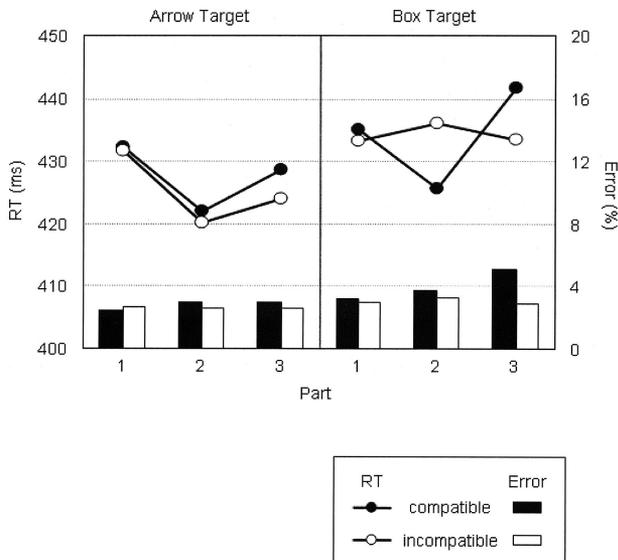


Figure 9. Mean reaction times (RTs; lines) and error rates (bars) on compatible (black) and incompatible (white) trials for each part of Experiment 2, separately for arrow target trials (left panel) and box target trials (right panel).

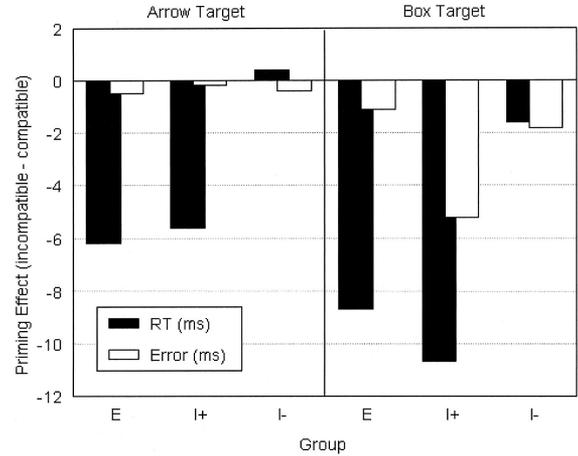


Figure 10. Priming effects (incompatible minus compatible) on reaction times (RTs in ms; black bars) and error rates (in %; white bars) in the last part of Experiment 2, separately for arrow target trials (left panel) and box target trials (right panel) and for explicitness groups (E = participants who gave a correct verbal report; I+ = participants who failed to give a correct verbal report but guessed correctly in the forced-choice task; I- = participants who failed to give a correct verbal report and guessed incorrectly in the forced-choice task).

RTs were slightly shorter on arrow target trials (426 ms) than on box target trials (434 ms),  $F(1, 17) = 17.49$ ,  $MSE = 207.36$ ,  $p = .001$  (two-tailed). There was no main effect of experimental part or compatibility (both  $F_s < 1.7$ ), but again there was a highly significant interaction between these variables,  $F(2, 34) = 6.25$ ,  $MSE = 68.95$ ,  $p = .008$ . This effect was further modified by a three-way interaction among part, compatibility, and target type,  $F(2, 34) = 4.88$ ,  $MSE = 63.34$ ,  $p = .015$  (two-tailed). Of note, none of these effects differed among explicitness groups. There was a slight but nonsignificant interaction between group and target type,  $F(2, 17) = 2.79$ ,  $MSE = 207.36$ ,  $p = .089$ , as participants in Group E tended to respond more slowly to box targets, but no other group effects even approached significance (all  $F_s < 1.7$ , all  $p_s > .19$ , two-tailed).

Subsequent analysis, conducted on RTs in each part separately, revealed that both target types failed to elicit compatibility effects in Part 1 (main effect of compatibility and Compatibility  $\times$  Target Type interaction: both  $F_s < 1$ ), and both showed significant NCEs in Part 3 (main effect of compatibility,  $F[1, 17] = 8.92$ ,  $MSE = 57.00$ ,  $p = .004$ , one-tailed; Compatibility  $\times$  Target Type,  $F < 1$ ). However, although arrow targets did not show any appreciable effect in Part 2, box targets showed a PCE (main effect of compatibility,  $F[1, 17] = 5.13$ ,  $MSE = 65.62$ ,  $p = .037$ , two-tailed; Compatibility  $\times$  Target Type,  $F[1, 17] = 10.67$ ,  $MSE = 55.78$ ,  $p = .005$ , two-tailed).

Discussion

These results confirm and extend the findings from Experiment 1: In an incidental learning situation, the shape of subliminally presented primes triggered motor priming effects even though stimulus shape was not part of the explicitly instructed task set but only covaried with the task-relevant stimulus feature. As in Ex-

periment 1, priming effects were not present from the outset of the experiment but developed over time, in line with the assumption that they were based on incidentally acquired representations of the shapes' potential task relevance.

The remaining data are also in good agreement between experiments. As in Experiment 1, (a) the majority of participants failed to acquire explicit, verbalizable knowledge about the color–shape relationship (76% in Experiment 1, 70% in the present experiment); (b) priming effects did not differ significantly among explicitness groups; (c) the only reliable indirect measure of color–shape learning was the RT difference between test block and preceding masked prime block (19 ms in Experiment 1, 16 ms in the present experiment); and (d) prime detection was drastically reduced for 17-ms primes relative to longer primes but was still higher than the false alarm rate.

With respect to explicitness scores, it is worth considering that this replication was achieved using a different procedure to probe explicit knowledge. Therefore, this result provides converging evidence for the assumption that color–shape learning in the present experiments was not only incidental but was in fact implicit in a substantial proportion of participants. This issue will be discussed in more detail in the General Discussion.

It is also noteworthy that although there was no statistically significant difference in priming effects across groups, there were hardly any NCEs in the present I– group (see Figure 10). However, it has to be remembered that these participants indicated an incorrect color–shape mapping in the forced-choice task. In fact, in the last part of the experiment, 2 of the 4 participants in this group produced PCEs (12 ms on average), whereas the other 2 produced NCEs (11 ms). This suggests there might be a possibility that 2 participants gave an incorrect response because they had formed a reversed implicit representation, whereas the other 2 had formed the correct implicit representation but could not access it consciously in the forced-choice task.

The most important difference between Experiment 1 and the present experiment was the increase in the number of box target trials from 10% to 25% in order to provide a sufficient number of these trials for statistical analysis. Surprisingly, box trials elicited a significant PCE in Part 2, for which we have as yet no explanation. Of note, however, arrow and box target trials elicited NCEs of similar magnitude in Part 3. In earlier studies, NCEs have been obtained with arrow primes and nonarrow targets (e.g., with unilaterally presented position targets; Eimer, 1999; Schlaghecken & Eimer, 2000; and even with nonspatial auditory targets; Klapp & Hinkley, 2002), provided these nonarrow trials were intermixed with arrow target trials. The present result is analogous to these earlier findings, providing converging evidence that the NCE reflects motor processes triggered by a masked prime, rather than perceptual interactions of primes and targets.

### General Discussion

Motor responses to visual stimuli might be triggered by a direct perceptuo-motor route, without requiring attentional top-down control processes (Neumann, 1989) or even the conscious perception of the triggering stimulus (Neumann & Klotz, 1994). Such direct links can be regarded as temporary configurations of the perceptuo-motor system that make it particularly susceptible to specific inputs and particularly likely to execute specific actions.

Although these configurations, once established, facilitate automatic processing, they might not themselves be established in an automatic, purely stimulus-driven way. For example, they strictly reflect the specific task set, that is, the set of S-R mappings required in the experiment (Ansorge et al., 2002; Eimer & Schlaghecken, 1998; Klapp & Haas, 2005; Klapp & Hinkley, 2002; Kunde et al., 2003; Neumann & Klotz, 1994; Schlaghecken & Eimer, 2004). In these studies, however, the relevant task set has always been implemented via explicit task instructions. The present study tested the hypothesis that direct perceptuo-motor links can be formed without explicit instruction, on the basis of incidentally acquired S-R mappings.

The present results fully confirm this hypothesis. In two experiments, participants responded to the color of differently shaped visual stimuli. Each target was preceded by a masked prime stimulus presented in a neutral, response-irrelevant color. When color and shape of the targets covaried, motor priming effects, triggered by the shape of the primes, developed over time (Experiment 1, CM group; Experiment 2). These effects were even obtained for targets that lacked the covarying shape feature (Experiment 2), confirming that they were elicited by the masked primes themselves, not by a perceptual interaction of masked prime and target. In contrast, no such effects occurred when target color and target shape varied independently (Experiment 1, control group). Together, these results suggest that the priming effects were based on an incidentally acquired task set, that is, on incidentally acquired representations of the shapes' potential task relevance.

Although the results are clear cut with respect to the experimental hypothesis, there are some issues that require further consideration. In particular, it seems surprising that relatively few participants showed explicit knowledge of the—rather simple—color–shape mapping. In order for one to account for this finding, it is crucial to distinguish between learning processes (the incidental acquisition of particular S-R contingencies) and the overt expression of these processes (priming effects and direct and indirect learning effects). This distinction has, of course, traditionally been made in the implicit learning literature, which is concerned with investigating learning processes that occur without the participants' awareness that they are learning something (for an overview, see, e.g., Cleeremans, Destrebecqz, & Boyer, 1998). In a typical implicit learning experiment, a serial RT task might be employed, where participants are presented with a repeated sequence of stimuli to which they have to give a corresponding repeated sequence of responses. At the end of the experiment, their explicit knowledge about this sequence is assessed. It is usually found that a substantial number of participants have not noticed the sequence and have no appreciable explicit knowledge about it. Nevertheless, during the experiment, these same participants showed significant behavioral costs when the sequence was altered (e.g., Eimer, Goschke, Schlaghecken, & Stürmer, 1996; Nissen & Bullemer, 1987; Schlaghecken, Stürmer, & Eimer, 2000), corresponding to the test block effects obtained in the present study.

It has to be noted, though, that the sequence structure in most serial RT studies is more complex than the simple one-to-one mapping employed here. Nevertheless, there usually seem to be at least some participants who acquire explicit, verbalizable knowledge about the sequence structure. Consequently, one might have expected that in the present study, the majority of participants—

rather than less than a third—should have been able to express explicit knowledge of the color–shape mapping. A possible explanation for these unexpectedly low numbers is that in typical serial RT tasks, participants acquire knowledge about response-relevant information: The same rules that determine the stimulus sequence also determine the corresponding response sequence. In the present study, in contrast, the color–shape mapping rules were not directly response relevant but merely determined the relationship between one response-relevant and one response-irrelevant stimulus feature. In a recent study, Hoffmann and Sebold (2005) have demonstrated that only a minority of participants (between 5% and 44% of the participants in six experiments) acquire explicit knowledge of this type of rule, even when the covarying feature is simple and participants attend to it. The authors argued that only “simultaneously activated distinct representations” (p. 449) will be associated with each other. Within the context of the present experiments, this would suggest that as long as participants did not pay sufficient attention to stimulus shape, it would not become associated with a particular color or response.

However, given the present results, this interpretation cannot be completely correct. If there had been no association between a particular shape and a particular response, then no priming effects would have been possible (this is especially true for box target trials, in which priming effects cannot be explained by perceptual interactions). It thus seems reasonable to assume that priming effects reflect an earlier stage of implicit perceptuo-motor learning than do overt responses to the covarying stimulus features, possibly because these effects are generated at low levels of perceptuo-motor processing and are—unlike the overt response—not affected by late-stage decision processes.

A second interesting aspect of the present data is the fact that priming effects occurred only toward the end of the experiment. This provides additional support for the claim that the NCE does not result from purely perceptual interactions of prime, mask, and target. In marked contrast to most masked prime studies with explicit task set instruction, in which NCEs are obtained from the first experimental block onwards (e.g., Eimer & Schlaghecken, 1998; but see Klapp & Haas, 2005; Klapp & Hinkley, 2002, for contrasting results), no NCEs occurred without prolonged exposure to a consistent color–shape mapping. This indicates that the NCE is not perceptual in nature: If it were due to a negative perceptual bias for repeated items (e.g., “repetition blindness”; Kanwisher, 1987), it should have been observed from the outset of the experiments, regardless of the presence or absence of a consistent color–shape mapping. The fact that this was not the case thus confirms earlier interpretations of the NCE in terms of low-level perceptuo-motor control processes (Schlaghecken et al., 2006; Schlaghecken & Eimer, 2002).

This is particularly relevant in light of the recent discussion about the role of the masking stimulus in eliciting NCEs. According to the model put forward by Schlaghecken and Eimer (2002; see also Bowman et al., 2006), the NCE reflects a self-inhibition process acting as an emergency brake when an initially activated, strong response tendency is suddenly no longer supported by sensory evidence. Results from functional magnetic resonance imaging (Aron et al., 2003) and repetitive transcranial magnetic stimulation (Schlaghecken, Münchau, Bloem, Rothwell, & Eimer, 2003) studies suggest that these processes occur upstream from the primary motor cortex, presumably involving basal ganglia–

thalamic–parietal cortical motor control circuits. Recently, however, alternative interpretations of the NCE have been put forward (Lleras & Enns, 2004; Verleger, Jaśkowski, Aydemir, van der Lubbe, & Groen, 2004), according to which the NCE reflects a sequence of initial prime-induced priming followed by masked-induced priming of the opposite response, without requiring any inhibition processes. These authors propose that NCEs are triggered by masks that share features with primes and targets (i.e., diagonal lines in the case of arrow primes and targets), because in such masks, novel features (i.e., those that were not already presented as part of the prime) are likely to be linked to the prime-opposite response. If these features come to dominate motor processing, then they will correspondingly trigger an activation of the opposite response. Although these alternative theories might be able to account for the present findings just as well as the self-inhibition model, it has to be noted that contrary to the claims made by Lleras and Enns (2004) and Verleger et al. (2004), recent evidence indicates that NCEs can be obtained reliably even when masks do not share any features with primes and targets (Klapp, 2005; Schlaghecken & Eimer, 2006). Furthermore, the masks used in the present experiments were deliberately designed to be as dissimilar to primes and targets as possible, while still providing successful masking: All line elements used to construct masks differed from the lines making up prime and target arrows in length and orientation. According to Sumner (in press), who systematically compared masks that did and did not share prime and target features and obtained NCEs in both cases, it is unlikely that with the present type of masking stimuli, mask-induced motor activation would have played a major role in generating the NCE.

In summary, the present results demonstrate that incidentally acquired S-R mappings are sufficient to allow response activations to be triggered by near-threshold stimuli. This suggests that explicit verbal instructions and incidentally acquired knowledge about stimulus contingencies might be different but equivalent means of configuring the perceptuo-motor system. These results fit well with recent neuroimaging studies investigating the time course of learning an arbitrary S-R mapping: Learning-related changes of neural activity in subcortical (basal ganglia) areas were found to occur concurrent with (Brasted & Wise, 2004) or even prior to (Pasupathy & Miller, 2005) corresponding changes in prefrontal cortical areas. Laubach (2005) suggested that during early stages of learning, relatively weaker signals from multiple cortical sources might be integrated by the striatum, which in turn “trains” specific task-related activity in prefrontal areas. The prefrontal cortex is generally assumed to be involved in conscious, higher level cognitive processes and explicit representations (“holding things in mind”; Frith & Dolan, 1996), whereas the basal ganglia are supposed to be involved in (nonconscious) automatic processing (e.g., Seth, Baars, & Edelman, 2005). The present results thus can be interpreted as indicating that in an incidental learning situation, perceptuo-motor learning initially involves configuration of the basal ganglia and related structures. There is some evidence indicating that the NCE is generated within these structures (e.g., Aron et al., 2003; Schlaghecken & Sisman, 2006). Only subsequently—and only in some participants—did these low-level changes generate higher level cognitive representations. The present results thus provide converging evidence that the NCE does not require top-down inhibitory control from frontal cortical areas but reflects processes within low-level (self-inhibitory) con-

trol circuits, which adjust their configuration to the current environment without the need for explicit instructions.

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### New Editors Appointed, 2009–2014

The Publications and Communications Board of the American Psychological Association announces the appointment of six new editors for 6-year terms beginning in 2009. As of January 1, 2008, manuscripts should be directed as follows:

- *Journal of Applied Psychology* (<http://www.apa.org/journals/apl>), **Steve W. J. Kozlowski, PhD**, Department of Psychology, Michigan State University, East Lansing, MI 48824.
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- *Behavioral Neuroscience* (<http://www.apa.org/journals/bne>), **Mark S. Blumberg, PhD**, Department of Psychology, University of Iowa, E11 Seashore Hall, Iowa City, IA 52242.
- *Psychological Bulletin* (<http://www.apa.org/journals/bul>), **Stephen P. Hinshaw, PhD**, Department of Psychology, University of California, Tolman Hall #1650, Berkeley, CA 94720. (Manuscripts will not be directed to Dr. Hinshaw until July 1, 2008, as Harris Cooper will continue as editor until June 30, 2008.)

**Electronic manuscript submission:** As of January 1, 2008, manuscripts should be submitted electronically via the journal's Manuscript Submission Portal (see the website listed above with each journal title).

Manuscript submission patterns make the precise date of completion of the 2008 volumes uncertain. Current editors, Sheldon Zedeck, PhD, Karen R. Harris, EdD, John F. Dovidio, PhD, Howard J. Shaffer, PhD, and John F. Disterhoft, PhD, will receive and consider manuscripts through December 31, 2007. Harris Cooper, PhD, will continue to receive manuscripts until June 30, 2008. Should 2008 volumes be completed before that date, manuscripts will be redirected to the new editors for consideration in 2009 volumes.