Journal of Experimental Psychology:
Learning, Memory, and Cognition
2009, Vol. 35, No. 1, 292–298

0278-7393/09/$12.00 DOI: 10.1037/a0014499

Playing Chess Unconsciously

Andrea Kiesel
University of Würzburg

Wilfried Kunde
University of Dortmund

Carsten Pohl, Michael P. Berner, and Joachim Hoffmann
University of Würzburg

Expertise in a certain stimulus domain enhances perceptual capabilities. In the present article, the authors investigate whether expertise improves perceptual processing to an extent that allows complex visual stimuli to bias behavior unconsciously. Expert chess players judged whether a target chess configuration entailed a checking configuration. These displays were preceded by masked prime configurations that either represented a checking or a nonchecking configuration. Chess experts, but not novice chess players, revealed a subliminal response priming effect, that is, faster responding when prime and target displays were congruent (both checking or both nonchecking) rather than incongruent. Priming generalized to displays that were not used as targets, ruling out simple repetition priming effects. Thus, chess experts were able to judge unconsciously presented chess configurations as checking or nonchecking. A 2nd experiment demonstrated that experts' priming does not occur for simpler but uncommon chess configurations. The authors conclude that long-term practice prompts the acquisition of visual memories of chess configurations with integrated form-location conjunctions. These perceptual chunks enable complex visual processing outside of conscious awareness.

Keywords: unconscious cognition, chess expertise, subliminal priming

What we see is determined by what we know. As the British psychologist Donald Broadbent once noted ironically, a very brief glimpse of a landscape suffices for a British observer to accurately detect that the sign "Don't step on the lawn!" is present.

Beyond ironical anecdotes like this, there is considerable experimental evidence showing that expertise in a task strongly improves perceptual skills, like the encoding of task-specific stimuli. Classical studies with chess experts by de Groot (1946/1966, 1978) and Chase and Simon (1973a, 1973b) showed that chess masters have the astonishing ability to reconstruct the locations of chess pieces from a game position almost perfectly, even if the chessboard was only briefly presented (2–15 s). On the basis of these results, Chase and Simon assumed that after playing chess for years, experts have acquired thousands of chunks for meaningful relations of chess pieces. These perceptual chunks are further integrated into larger long-term memory structures, which are called templates (for the original chunking theory, see Chase & Simon, 1973a, 1973b; for the template theory, see Gobet & Simon, 1996, 2000; however, see Ericsson & Kintsch, 1995, for an alternative long-term working memory theory).

Within the same line of reasoning, there is new evidence for task-specific perceptual encoding advantages. For example, Reingold, Charness, Pomplun, and Stampe (2001) observed that skilled chess players encode larger portions of chessboards during each fixation than chess novices. Moreover, Reingold, Charness, Schultetus, and Stampe (2001) demonstrated that experts encode chess relations automatically and in parallel. They applied a check detection task on a 5 × 5 square segment of a chessboard. Participants were asked to indicate whether a cued attacker checks the king. In addition, a second attacker was presented that was not relevant for the instructed task. Nevertheless, this distractor check piece was processed because responding was slower when the second attacker was incongruent (i.e., was checking while the cued attacker was nonchecking) rather than congruent to the cued one, reflecting a Stroop-like interference effect. These and similar findings led to the conclusion that perceptual superiority is a fundamental component of expertise (e.g., Charness, Reingold, Pomplun, & Stampe, 2001; de Groot & Gobet, 1996; Saariluoma, 1985; for an overview, see Gobet & Charness, 2006).

In the present study, we explored the limits of expertise-based perceptual improvements. We tested whether expertise in chess has the power to enable cognitive processes that are normally linked to conscious experience to run outside of awareness. To investigate processing outside of awareness, we applied a subliminal priming task (e.g., Dehaene et al., 1998; Marcel, 1983; Neumann & Klotz, 1994). In such tasks, participants are required to perform a speeded two-choice response on the basis of a clearly visible target stimulus. Prior to the target, another stimulus (the so-called prime) is presented. The prime either affords the same or the alternative response as the target—meaning it is congruent or incongruent to the target. Most important, presentation time of the

Andrea Kiesel, Carsten Pohl, Michael P. Berner, and Joachim Hoffmann, Department of Psychology, University of Würzburg, Würzburg, Germany; Wilfried Kunde, Department of Psychology, University of Dortmund, Dortmund, Germany.

This work was supported by Deutsche Forschungsgemeinschaft Grants HO 1301/10-1, KI 1388/1-2, and Ku 1964/1-1,2 awarded to Joachim Hoffmann, Andrea Kiesel, and Wilfried Kunde.

Correspondence concerning this article should be addressed to Andrea Kiesel, Department of Psychology, University of Würzburg, Röntgenring 11, 97070 Würzburg, Germany. E-mail: kiesel@uni-wuerzburg.de

prime is very short, and additionally the prime is masked so that participants are not aware of the prime. Nevertheless, this unconsciously presented stimulus is processed because responding to the target is faster and less error prone after congruent primes compared with incongruent primes.

Specifically, we investigated whether chess experts are able to recognize rapidly, and entirely unconsciously, whether a briefly presented chess situation entails a checking configuration. Such a finding would be important in two respects. First, research on unconscious response priming suggests that beyond simple perceptual classifications (Neumann & Klotz, 1994; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003), several cognitive processes can be applied to subliminal stimuli as well. Recent examples include the judgment of numerical size of numbers (Dehaene et al., 1998), the classification of letters as vowels and consonants (Kiesel, Kunde, & Hoffmann, 2007b; Reynvoet, Gevers, & Caessens, 2005), and the evaluation of words as positive or negative (Klauer, Eder, Greenwald, & Abrams, 2007) or as denoting small or large objects (Kiesel, Kunde, Pohl, & Hoffmann, 2006). The necessary operations to solve these tasks can be construed as being well-trained (either explicitly as in counting or implicitly as in reading), suggesting that practice might be an important prerequisite of subliminal processing (e.g., in the case of reading, letters are automatically integrated and form word "chunks"). Yet, to the best of our knowledge, this conjecture has never been tested directly. Demonstrating differential effects of subliminal stimuli for participants who do or do not posses high amounts of practice with a certain stimulus domain would strongly support the view that practice is a crucial determinant of unconscious processing.

Second, the specific example investigated here would be remarkable because the evaluation of a checking configuration requires solving an exclusive or (XOR) task (a detailed description of the task is given below) and therefore requires conjointly combining two stimulus features, such as the identity of the chess pieces and their spatial location in relation to the king. Such feature integration has been assumed to require attention (Treisman, 1996). Moreover, theoretical work by Engel and Singer (2001) as well as empirical work by Tapia and Breitmeyer (2006) previously suggested that feature integration is confined to consciously identified stimuli. From a neurophysiologic perspective, feature integration is required when different features are processed and represented in different neuronal assemblies. Feature binding is assumed to be due to temporal (gamma) synchronization of neuronal activity. Recently, Engel and Singer considered gamma synchronizations as the neuronal correlate for conscious representation. Consequently, feature binding has been assumed to be confined to consciously presented stimuli. However, demonstrating unconscious check detection would challenge this view, or would at least call for an explanation without assuming feature integration. We come back to this issue in Experiment 2.

Experiment 1

We compared the performance of chess experts and chess novices in the subliminal priming task illustrated in Figure 1. Stimuli were 3 × 3 chessboards that either displayed a checking or a nonchecking configuration. The king was always presented in the upper left corner, and the attacker was either rook or knight. Participants carried out one response upon identifying a checking position and another response upon identifying a nonchecking configuration (for similar check detection tasks, see Reingold, Charness, Pomplum, & Stampe, 2001; Saariluoma, 1985). For example, a rook displayed in the upper right corner represents a checking configuration (see Figure 1, Panel A), whereas a knight displayed in the upper right corner represents a nonchecking configuration (see Figure 1, Panel B). In contrast, a rook displayed in the lower middle square represents a nonchecking configuration (see Figure 1, Panel D), whereas a knight displayed in the lower middle square (see Figure 1, Panel C) represents a checking configuration. Thus, the applied check detection task constitutes an XOR problem because two displays require the same response (i.e., are congruent) either when both features, identity and location in relation to the king, are the same or both differ—whereas two displays require different responses (i.e., are incongruent) if one feature is repeated while the other changes. Before each target configuration, a prime configuration was shown briefly and masked immediately so that participants were unable to consciously perceive the prime configurations. The accurate processing of the unconscious configuration would be indicated by a response priming effect, that is, faster responses when both prime and target configurations were checking or both were nonchecking (congruent trials) than when one configuration was checking but the other was not (incongruent trials).

In addition, half of the prime configurations were never used as target stimuli, that is, participants never categorized them consciously. These "novel" primes were included to rule out that response priming resulted merely from acquired stimulus–response links that evolved in the course of the experiment when participants repeatedly responded to the consciously seen targets (Abrams & Greenwald, 2000; Damian, 2001).

Method

Participants. Twelve chess players (18–50 years of age; DWZ[1] scores = 1,346–2,150; M = 1,746,[2] SD = 215) and 24 chess novices (20–45 years of age; inexperienced chess players who reported having played no more than 100 games) participated each in an individual session of approximately 55 min. All participants declared having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

Apparatus and stimuli. An IBM-compatible computer with a 17-in. (43.18-cm) VGA display (vertical retraces 100 Hz) and an external keyboard were used for stimulus presentation and response sampling. Stimuli were eight pictures of minimized 3 × 3 chessboards extending 45 × 45 mm. The king was always located in the upper left corner. The attacker, either rook or knight, was located in one of four positions (upper right, middle right, lower left, and lower middle square). Four of the chessboards (rook or knight located in the upper right or lower middle square) served as targets. All eight chessboards were used as primes, enabling us to

[1] DWZ is the abbreviation for "Deutsche Wertungszahl," which is the rating of the German chess federation; the rating roughly matches ELO ratings.

[2] Most of the chess players that participated in Experiments 1 and 2 would be categorized as intermediate players in chess ranking; we use the term *experts* to contrast their experience with our novices.

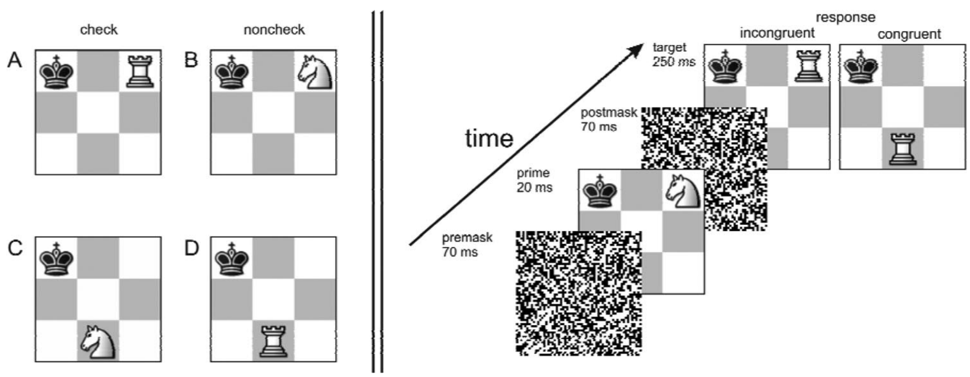

Figure 1. Stimulus material (left): 3 × 3 grids either displayed a checking configuration (Panels A and C) or a nonchecking configuration (Panels B and D). Experimental procedure (right): On each trial, premask, prime, postmask, and target were presented. Participants indicated whether the target displayed a checking or a nonchecking configuration. In half of the trials, the prime was response congruent (prime and target would require the same responses). Primes were either also presented as targets (target primes) or they were novel stimuli (novel primes).

compare the effects of novel and target primes. Masks were random dot patterns extending 80 × 80 mm.

Design and procedure. Each trial started with an empty 3 × 3 grid with a fixation cross in the middle presented for 400 ms. Premask, prime, postmask, and target were then presented. To enhance masking, premask and postmask, we had each of these categories consist of three different random dot patterns presented for 30, 20, and 20 ms. Prime duration was 20 ms; target duration was 250 ms. Participants were instructed to indicate whether the target displayed a checking or a nonchecking configuration by pressing a left key or a right key. Errors and missing responses (exceeding 5 s after target onset) were fed back.

The experiment consisted of 10 blocks in which each combination of Prime (8) × Target (4) was presented twice in random order. It finished with a detection task to test participants' awareness of the primes. Participants were fully informed about the structure of the prime stimuli and were then presented with 128 identical trials for which they were to discriminate whether the prime displayed a checking or a nonchecking configuration.

Results

Congruency effect. Trials with reaction times (RTs) deviating more than 2.5 standard deviations from the mean RT of each participant and each experimental condition (2.1%) were excluded. Mean RTs for correct responses and error rates for each combination of the factors prime congruency and prime type for experts and novices are given in Table 1.

An analysis of variance (ANOVA) on RTs for correct responses with the between-subjects factor expertise and with the within-subject factors prime congruency and prime type revealed significant main effects for expertise, $F(1, 34) = 9.3$, $p < .01$, $\eta_p^2 = .21$, and prime congruency, $F(1, 34) = 8.4$, $p < .01$, $\eta_p^2 = .20$, as well as a significant interaction between expertise and prime congruency, $F(1, 34) = 10.5$, $p < .01$, $\eta_p^2 = .24$. The same ANOVA on error rates revealed no significant effects (ps $> .17$). A separate ANOVA[3] revealed that chess experts responded 11 ms faster with congruent primes compared with incongruent primes, $F(1, 11) = 17.7$, $p < .01$, $\eta_p^2 = .62$. Neither the main effect of prime type nor the interaction between both factors was significant (ps $> .21$). For chess novices, the same ANOVAs on RTs revealed no significant effects (ps $> .47$).

On average, chess players responded much faster than chess novices (529 ms vs. 626 ms), replicating previous findings by Jastrzembski, Charness, and Vasyukova (2006); Reingold, Charness, Pomplum, and Stampe (2001); and Saariluoma (1985) that skilled chess players are faster in a check detection task than novices. Thus, one might suspect that there was no congruency effect for chess novices because the prime-induced activation had already faded. To rule out this suspicion, we examined RT distributions on the basis of percentile values obtained for each participant (we chose percentiles of 5%, 15%, . . . , 95%). If prime-induced activation had faded for longer RTs, we would expect no congruency effect for higher percentiles in the experts' data, whereas for novices a congruency effect should turn up in the lower percentiles. This is clearly not the case (see Figure 2).

Prime visibility. Participants' discrimination performance for check versus noncheck primes was $d' = 0.05$ for chess players and $d' = -0.02$ for novices and did not deviate significantly from zero (ps $> .45$). To test whether the priming effect of the experts is related to individual prime visibility, we computed a regression analysis as proposed by Draine and Greenwald (1998; see also Greenwald, Draine, & Abrams, 1996; Greenwald, Klinger, & Schuh, 1995). A priming index was calculated for each participant, with index = 100 × (RT incongruent − RT congruent)/RT congruent. Individual priming indices were regressed onto the individual d' values. The linear regression analysis revealed no significant correlation between d' and the priming index ($r = .230$), $F(1, 11) = 0.56$, $p > .47$, whereas the intercept of the regression was larger than zero (intercept = 2.18), $t(11) = 4.41$, $p < .01$, indicating that significant priming effects are associated with d' values of zero.

[3] Further separate ANOVAS revealed that the congruency effect for experts did not differ between experimental halves ($p = .49$) or between checking and nonchecking displays ($p = .17$).

Table 1
Mean RTs (in Milliseconds) and Percentages of Errors for Congruent and Incongruent Primes and the Resulting Congruency Effects for Target and Novel Primes in Experiments 1 and 2

	Experiment 1		Experiment 1		Experiment 2	
	Experts		Novices		Experts	
Variable	Target primes	Novel primes	Target primes	Novel primes	Target primes	Novel primes
RTs						
Incongruent prime	536 (15.0)	534 (15.7)	624 (21.0)	627 (22.2)	681 (20.9)	675 (18.7)
Congruent prime	521 (14.2)	526 (15.2)	626 (19.9)	627 (21.9)	677 (21.3)	674 (19.8)
Congruency effect	14**	8*	−1	0	3	1
Error rates[a]						
Incongruent prime	7.5 (1.2)	7.6 (1.5)	6.6 (0.99)	6.3 (0.82)	10.4 (1.7)	10.1 (1.6)
Congruent prime	7.3 (1.3)	7.0 (1.5)	6.8 (0.98)	7.5 (1.1)	10.5 (1.9)	10.1 (1.6)

Note. Corresponding standard errors are shown in parentheses. Discrepancies in the computed congruency effect result from rounding errors. RTs = reaction times.
[a] There were no significant congruency effects for error rates.
* $p < .05$. ** $p < .01$.

Discussion

Unconsciously presented chessboard configurations significantly influenced experts' check detection performance. Participants responded faster when both chessboards required the same response compared with a different response. Even novel primes—that is, chess configurations that were never presented as targets in the experiment—yielded priming effects. This observation rules out that priming resulted from stimulus–response links that were acquired in the course of the experiment because participants repeatedly performed the same response upon a target stimulus (e.g., Damian, 2001; for a more elaborate discussion, see Kiesel, Kunde, & Hoffmann, 2007a; Kunde, Kiesel, & Hoffmann, 2003). Instead, chess experts were able to rapidly judge chess configurations as checking or nonchecking even for unconsciously presented check configurations. In contrast, novices did not reveal a subliminal response priming effect.

Regarding the nature of the observed priming effect—that is, the question whether congruent primes facilitate responding and/or incongruent primes interfere with performing the alternative response—we can currently just speculate. In subliminal priming studies that used a baseline condition, researchers observed facilitation effects by congruent primes as well as interference effects by incongruent primes (e.g., Neumann & Klotz, 1994). Electrophysiological as well as functional imaging studies (e.g., Dehaene et al., 1998; Eimer & Schlaghecken, 2003; Leuthold & Kopp, 1998) revealed that the subliminally presented prime triggers motor activation of the task-assigned response. In the case of congruent primes, responding to the target is facilitated because the currently required response is preactivated by the prime, whereas in the case of incongruent primes, the alternative response is preactivated and interferes with response execution. Yet, for the applied check detection task, it is currently unclear whether the chess configurations presented as primes also trigger the task-assigned motor response. Alternatively, one might assume that the observed priming effects are merely due to facilitation effects that take place on a more conceptual level.

Irrespective of the exact mechanisms underlying the observed priming effects, these results are striking because check detection nominally requires conjointly considering the location and the identity of the attacker. If participants merely took into account one feature of the unconscious prime—that is, either location (e.g., the attacker is presented in the right upper corner; see Figure 1, Panels A and B) or identity of the attacker (e.g., rook; see Figure 1, Panels A and D)—primes could not be categorized as checking or nonchecking. Thus, apparently experts, but not novices, show rapid integration of two stimulus features despite their having been presented unconsciously. This would mean that experts differ from novices fundamentally regarding the ability to integrate features of unconsciously presented stimuli.

Yet, there is another explanation that does not require postulating such a fundamental difference of cognitive processing. Basically this account assumes that expertise allows experts to bypass cognitive operations by relying instead on memories of stored task solutions (Chase & Simon, 1973a, 1973b; Gobet & Simon, 1996, 2000; for a general theory of automaticity, see Logan, 1988). This account holds that experts acquired perceptual chunks[4] for typical chess configurations during intensive training—most likely especially for the most important configurations in which the king is immediately threatened by an attacker (see, e.g., McGregor & Howes, 2002, for the importance of attack–defense relations). Conceivably, these perceptual chunks represent integrated memories in which the features of chess pieces' identities and their spatial relations are already bound together. To the extent that an encountered configuration matches a stored checking configuration, the associated "checking" motor response is triggered (cf. Kunde et al., 2003).

If this second alternative holds true, chess experts should not reveal subliminal priming effects if the response decision does not rely on acquired perceptual chunks of chess configurations. This assumption was tested in Experiment 2.

[4] We use the term *perceptual chunks* to stress the process of perceptual learning. Within this sense, perceptual chunks are photograph-like images of known objects stored in memory (Goldstone, 1998). This meaning is equivalent to the use of the term perceptual chunks in the chunking theory and the template theory in the field of chess expertise.

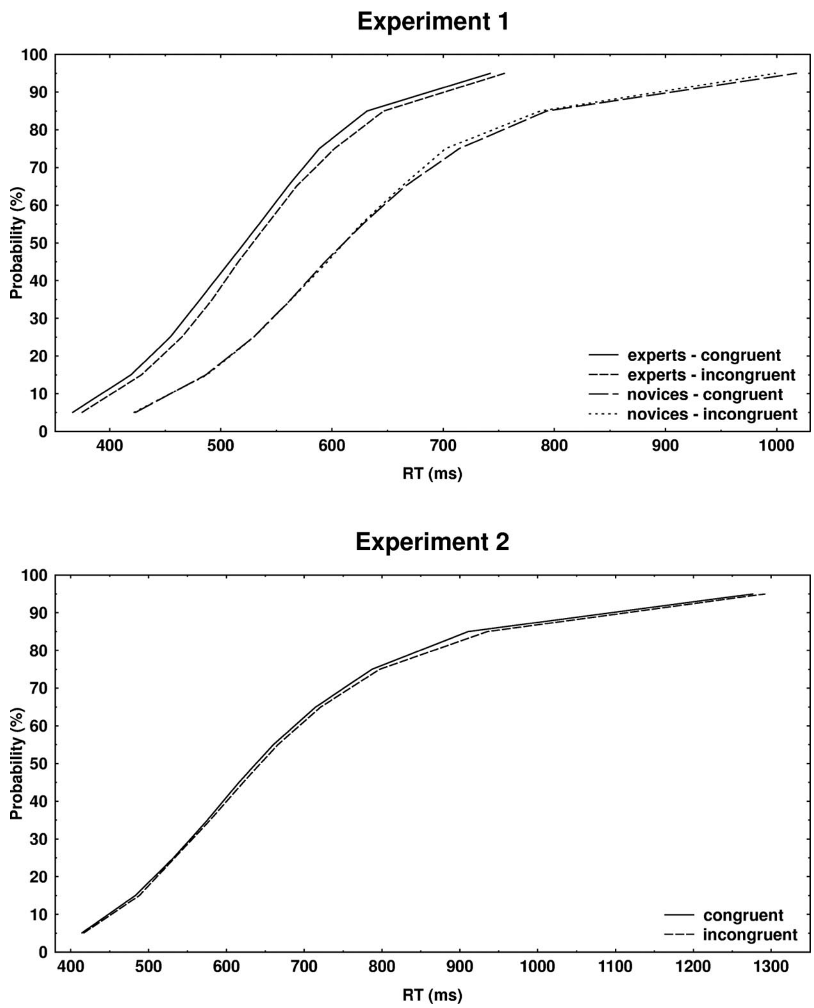

Figure 2. Reaction-time (RT) distributions (estimated from 5%, 15%, . . ., 95% percentile values gained by means of interpolation) depending on congruency for Experiments 1 and 2. Chess experts performing a check detection task (Experiment 1) revealed significant response congruency effects over all percentiles except the last one (i.e., 95% percentile). Novices in Experiment 1 and experts performing a feature conjunction task (Experiment 2) did not reveal response congruency effects for any percentile.

Experiment 2

The same 3 × 3 grids as in Experiment 1 were used. However, instead of a checking configuration or a nonchecking configuration, only one single chess piece, either rook or knight, was presented. Participants were instructed to press one response key if the rook was presented on a white field or the knight was presented on a black field, and the alternative response key if the rook was presented on a black field or the knight was presented on a white field. Again a masked prime was presented prior to each target that either required the same response (congruent trials) or the alternative response (incongruent trials) as the target. The processing of this task could not rely on the well-trained checking or nonchecking decision, but it required integrating location and identity of the chess piece. If the expert-based priming effects in Experiment 1 are based on more efficient feature-integration processes, subliminal priming effects should ensue. If, however, these effects are mediated by meaningful chunks of chess configurations (Gobet & Simon, 1996), no priming should arise because single figure displays do not entail meaningful relations of chess pieces.

Method

Participants. Twelve chess players (18–50 years of age; DWZ scores = 1,384–2,227; $M = 1{,}750$, $SD = 292$) participated each in an individual session of approximately 55 min. None of them had participated in Experiment 1.

Apparatus, stimuli, design, and procedure. Experiment 2 was similar to Experiment 1 except for the following: In the 3 × 3 grids, just a rook or knight was located in one of four positions (upper right, middle right, lower left, and lower middle square). Thus, the used target and prime displays were exactly the same as before but without the king. Likewise, the same response was required upon the identity and location of the chessman. However, instead of performing a check detection task, participants were instructed to respond to press one response key if the rook was presented on a white field or the knight was presented on a black field, and the alternative response key if the rook was presented on a black field or the knight was presented on a white field.

Results

Congruency effect. Trials with RTs deviating more than 2.5 standard deviations from the mean RT of each participant and each experimental condition (2.8 %) were excluded. Mean RTs for correct responses and error rates for each combination of the factors prime congruency and prime type are given in Table 1.

An ANOVA on RTs for correct responses with the factors prime congruency and prime type revealed no significant effect (ps $>$ .54). Neither target primes nor novel primes induced a significant congruency effect (separate *t*-tests revealed ps $>$ .72). The same ANOVA on error rates also revealed no significant effects (ps $>$ .69).

Responding in this task took much longer on average than in Experiment 1. To rule out that a possible priming effect faded with longer RTs, we again examined RT distributions. Inspection of the lower panel in Figure 2 clearly rules out this alternative.

Prime visibility. Participants' discrimination performance for check versus noncheck primes was $d' = 0.047$ and did not deviate significantly from zero ($p > .56$).

Discussion

Chess experts do not reveal subliminal priming effects in a task that requires integrating location and identity of a single chess piece. Thus, we rule out that chess experts are capable of rapidly integrating the features of subliminally presented chess pieces.

General Discussion

Expert chess players showed subliminal priming in a task that nominally requires feature integration, but they could rely on stored chess configurations, whereas they showed no priming in a task that requires the integration of stimulus features, but they could not rely on stored chess configurations. This suggests that experts' priming effects are brought about by acquired perceptual chunks that incorporate integrated features of chess pieces' identities and locations. The results extend current knowledge regarding perceptual superiority of experts. Previous studies demonstrated that processing of clearly visible stimuli is automatic because participants were not able to suppress processing of irrelevant distractor check pieces (Reingold, Charness, Schultetus, & Stampe, 2001). Here, we demonstrate that chess experts process chess configurations even when presented unconsciously.

Taken together, the present study also extends our knowledge on unconscious information processing. We have shown that expertise in a certain domain is an important determinant of unconscious processing. Such an observation might be predicted on the basis of previous studies on subliminal priming because these studies used well-known stimulus material (such as easy geometrical forms, digits, words, pictures) for which everybody can be considered to be an expert. Our results suggest that an enormous amount of practice is necessary to enable unconscious stimulus processing because chess novices did not reveal subliminal priming effects for target primes, that is, for chess configurations that they have seen repeatedly as targets during the experiment.

In addition, chess experts did not reveal subliminal priming effects in Experiment 2. Obviously at least one condition for expert-specific priming was not met here. These might be the use of stimuli that contained no meaningful relationship between chess pieces or the use of an untypical task (explicitly combing identity and location of chess pieces instead of evaluating the chess configuration). Thus, probably unconscious stimulus processing is restricted to well-trained material and depends on the relevance of the instructed task.

Furthermore, our findings suggest that this impact of expertise on unconscious stimulus processing is unlikely to be mediated by the improvement of task-specific cognitive processes (integration of stimulus features), but instead it appears to be based on the substitution of such processes through acquired memories. Expertise thus not only improves task performance but it might also change the nature and phenomenal experience of performing a task by becoming increasingly unconscious.

References

Abrams, R. L., & Greenwald, A. G. (2000). Parts outweigh the whole (word) in unconscious analysis of meaning. *Psychological Science, 11,* 118–124.

Charness, N., Reingold, E. M., Pomplun, M., & Stampe, D. M. (2001). The perceptual aspect of skilled performance in chess: Evidence from eye movements. *Memory & Cognition, 29,* 1146–1152.

Chase, W. G., & Simon, H. A. (1973a). The mind's eye in chess. In W. G. Chase (Ed.), *Visual information processing* (pp. 215–281). New York: Academic Press.

Chase, W. G., & Simon, H. A. (1973b). Perception in chess. *Cognitive Psychology, 4,* 55–81.

Damian, M. F. (2001). Congruity effects evoked by subliminally presented primes: Automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 154–165.

de Groot, A. D. (1966). *Het denken van den schaker* [Thought and choice in chess]. New York: Basic Books. (Original work published 1946)

de Groot, A. D. (1978). *Thought and choice in chess* (2nd ed.). The Hague, the Netherlands: Mouton.

de Groot, A. D., & Gobet, F. (1996). *Perception and memory in chess.* Assen, the Netherlands: Van Gorcum.

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., et al. (1998, October 8). Imaging unconscious semantic priming. *Nature, 395,* 597–600.

Draine, S. C., & Greenwald, A. G. (1998). Replicable unconscious semantic priming. *Journal of Experimental Psychology: General, 127,* 286–303.

Eimer, M., & Schlaghecken, F. (2003). Response facilitation and inhibition in subliminal priming. *Biological Psychology, 64,* 7–26.

Engel, A. K., & Singer, W. (2001). Temporal binding and the neural correlates of sensory awareness. *Trends in Cognitive Sciences, 5,* 16–25.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102,* 211–245.

Gobet, F., & Charness, N. (2006). Expertise in chess. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 523–538). Cambridge, MA: Cambridge University Press.

Gobet, F., & Simon, H. A. (1996). Templates in chess memory: A mechanism for recalling several boards. *Cognitive Psychology, 31,* 1–40.

Gobet, F., & Simon, H. A. (2000). Five seconds or sixty? Presentation time in expert memory. *Cognitive Science, 24,* 651–682.

Goldstone, R. L. (1998). Perceptual learning. *Annual Review of Psychology, 49,* 585–612.

Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996, September 20). Three cognitive markers of unconscious semantic activation. *Science, 273,* 1699–1702.

Greenwald, A. G., Klinger, M. R., & Schuh, E. S. (1995). Activation by marginally perceptible ("subliminal") stimuli: Dissociation of unconscious from conscious cognition. *Journal of Experimental Psychology: General, 124,* 22–42.

Jastrzembski, T., Charness, N., & Vasyukova, C. (2006). Expertise and age effects on knowledge activation in chess. *Psychology and Aging, 21,* 401–405.

Kiesel, A., Kunde, W., & Hoffmann, J. (2007a). Mechanisms of subliminal response priming. *Advances in Cognitive Psychology, 3,* 307–315.

Kiesel, A., Kunde, W., & Hoffmann, J. (2007b). Unconscious priming according to multiple S–R rules. *Cognition, 104,* 89–105.

Kiesel, A., Kunde, W., Pohl, C., & Hoffmann, J. (2006). Priming from novel masked stimuli depends on target set size. *Advances in Cognitive Psychology, 2,* 37–45.

Klauer, C., Eder, A., Greenwald, A. G., & Abrams, R. (2007). Priming of semantic classifications by novel subliminal prime words. *Consciousness and Cognition, 16,* 63–83.

Kunde, W., Kiesel, A., & Hoffmann, J. (2003). Conscious control over the content of unconscious cognition. *Cognition, 88,* 223–242.

Leuthold, H., & Kopp, B. (1998). Mechanisms of priming by masked stimuli: Inferences from event-related brain potentials. *Psychological Science, 4,* 263–269.

Logan, G. (1988). Toward an instance theory of automatization. *Psychological Review, 95,* 492–527.

Marcel, A. J. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology, 15,* 197–237.

McGregor, S. J., & Howes, A. (2002). The role of attack and defense semantics in skilled players' memory for chess positions. *Memory & Cognition, 30,* 707–717.

Neumann, O., & Klotz, W. (1994). Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In C. Umilta & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 123–150). Cambridge, MA: MIT Press.

Reingold, E. M., Charness, N., Pomplum, M., & Stampe, D. M. (2001). Visual span in expert chess players: Evidence from eye movements. *Psychological Science, 12,* 48–55.

Reingold, E. M., Charness, N., Schultetus, R. S., & Stampe, D. M. (2001). Perceptual automaticity in expert chess players: Parallel encoding of chess relations. *Psychonomic Bulletin and Review, 8,* 504–510.

Reynvoet, B., Gevers, W., & Caessens, B. (2005). Unconscious primes activate motor codes through semantics. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 991–1000.

Saariluoma, P. (1985). Chess players' intake of task-relevant cues. *Memory & Cognition, 13,* 385–391.

Tapia, E., & Breitmeyer, B. G. (2006). Attentional processing capacities of the visual "zombie" and "homunculus" [Abstract]. *Abstracts of the Psychonomic Society, 47th Annual Meeting, 11,* 8.

Treisman, A. (1996). The binding problem. *Current Opinion in Neurobiology, 6,* 171–178.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *Proceedings of the National Academy of Sciences, USA, 100,* 6275–6280.

Received February 28, 2008
Revision received September 23, 2008
Accepted October 12, 2008 ■