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ERP to chess stimuli reveal expert-novice differences in the amplitudes of N2 and P3

components

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Abstract

ERP experiments were conducted to analyze the underlying neural events when chess players make simple judgments of a board position. Fourteen expert players and 14 age-matched novices viewed, for each of four tasks, 128 unique positions on a mini (4 × 4) chess board each presented for 0.5 s. The tasks were to respond: (a) if white king was in check, (b) if black knight was present, (c) if white king was not in check, and (d) if no black knight was present. Experts showed an enhanced N2 with check targets and a larger P3 with knight targets, relative to novices. Expert-novice differences in posterior N2 began as early as 240 ms on check-related searches. Results were consistent with the view that prolonged N2 components reflect matching of current perceptual input to memory, and thus are sensitive to experts' superior pattern recognition and memory retrieval of chunks.

Keywords: individual differences, cognition, ERP/EEG, expertise.

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The study of expertise has given rise to at least three substantial fields: the 'classic' study of expertise, started by de Groot (1965) and continued among many others by Chase and Simon (1973), the field of *perceptual learning*, influenced by Gibson and Gibson (1955), and more recently *perceptual expertise*, carried out mostly in neuroscience (Gauthier, Tarr, & Bub, 2009; Tanaka & Curran, 2001). While much emphasis has been placed on the role of perception in these fields, it is also acknowledged that in many domains abstract, semantic knowledge plays an important role, often but not always in tandem with perceptual skills (Chassy & Gobet, 2011; Herzmann & Curran, 2011).

Chase and Simon (1973) demonstrated that expert chess players show superior pattern recognition and an enhanced ability to memorize chess positions. In their "chunking theory," they proposed that experts acquire a large number of chunks in long-term memory through practice and study, which enables them to recognize chess patterns on the boards rapidly and automatically. As some of these chunks are linked to potentially good moves, pattern recognition also makes it possible for experts to rapidly identify useful moves in a given position.

Template theory (Gobet & Simon, 1996, 2000), which is implemented as a computer program, is a development of chunking theory in which chunks are elaborated through extended practice into knowledge structures consisting of core information supplemented with slots into which new information can be rapidly encoded. Templates play an important role in linking perceptual knowledge to semantic knowledge. The perceptual, learning, and memory mechanisms postulated by template theory are general and have been shown to explain phenomena beyond chess, in domains such as categorization, implicit learning, problem solving, decision making, and the acquisition of language (Gobet et al., 2001; Gobet & Lane, 2010).

These mechanisms can account for both object recognition and scene recognition, in which the emphasis is on the relations between objects. Template theory has successfully predicted the skill differences found in chess players, including rapid recognition of board positions, type of errors made, and eye movements, in a range of studies (Gobet & Simon, 1996, 2000; Gobet & Waters, 2003; de Groot & Gobet 1996; Waters & Gobet, 2008).

Previous studies using fMRI implicate a distributed network of brain areas in chess expertise. Activation in frontal and parietal lobe areas concerned with working memory was observed during delayed matching to sample of chess positions. In a purely perceptual task, contrasts between chess game stimuli and randomized or nonchess control patterns revealed activation in ventral temporal lobe areas suggesting that chess chunks are stored in these regions (Campitelli, Gobet, Head, Buckley, & Parker, 2007). Furthermore, expert chess players showed fMRI activation in left superior temporal, inferior parietal and frontal regions when viewing chess positions from games in which they had taken part, compared with positions from other games (Campitelli, Parker, Head, & Gobet, 2008). In comparing normal versus randomized board positions, activation was localized to a small bilateral area in the collateral sulcus, which may be specialized for encoding the spatial relationships between objects (Bilalić, Langner, Erb, & Grodd, 2010). Differential fMRI responses in expert and novice players have been found in many of the above areas (Bilalić et al., 2010; Bilalić, Kiesel, Pohl, Erb & Grodd, 2011; Bilalić, Turella, Campitelli, Erb, & Grodd, 2012; Campitelli et al., 2009). Because expert chess judgments can be very rapid (Gobet & Simon, 2000), we predicted that neural correlates of expertise could also be demonstrated in the time ranges measurable by ERP.

Although chess experts show superiority for recognition of chess stimuli, it is already known that they have no general visual object recognition superiority (Bilalić et al., 2010; 2011; 2012). There is however a substantial ERP literature from nonchess object recognition paradigms, including other domain-specific expertise effects (Abdel Rahman & Sommer, 2008; Curran et al., 2009; Friedman, 1990; Hertzmann & Curran, 2011; Rugg & Curran, 2007; Tanaka & Curran, 2001). An important conclusion from these studies is that semantic knowledge influences both object recognition and its ERP correlates. This literature forms a basis for interpreting chess ERPs.

Visual search among an array of objects also plays a role in chess expertise. It has been extensively studied with nonchess stimuli using ERP methods (Akyürek, Dinkelbach, Schubö, & Müller, 2010; Fox, Michie, Wynne, & Maybery, 2000; Hillyard & Annlo-Vento, 1998; Woodman & Luck, 2003; Wykowska & Schubö, 2009). These studies mainly concern identification of a target among distractors where the spatial relationship of objects is unimportant, unlike the situation in chess. Furthermore, in chess, valid spatial configurations of pieces have a functional meaning, but ERPs to functional spatial relationships of objects have been little studied.

We therefore designed an ERP study to compare chess tasks involving simple object recognition, that is, identification of the presence of a specific chess piece, with tasks requiring identification of a functional spatial relationship between identified pieces. Template theory predicts that experts should be superior to novices in perception and memory for chess stimuli, and also that expert-novice differences should be greater for valid chess patterns of greater complexity (Gobet & Simon, 1996; 2000). We set out to test the following hypotheses: (a) there are expert-novice

differences in amplitudes of ERP components to chess stimuli; (b) expert-novice

differences are larger for tasks that involve recognition of a functional and spatial

relationship between objects, i.e., "is the white king in check?", and smaller for

identification of a particular object, i.e., "is there a black knight on the board?"; and

(c) there are differences in ERP latency between expert and novice players that reflect

differences in processing time. These three hypotheses derive from template theory.

Because there are asymmetries between target-present and target-absent visual search

(Akyürek et al., 2010; Treisman & Gelade, 1986), we add the following exploratory

hypothesis: (d) there are ERP differences for experts versus novices in target-present

(e.g., "respond if the king is in check") and target-absent (e.g., "respond if the king is

not in check") searches.

Method

Participants

Forty-two right-handed male participants were tested, of whom 14 were

experts (M age = 44.4 years, SD = 10.9, range 23 – 66), and 28 were novices (M age

= 31.9 years, SD = 10.9, range 18 – 61). An age-matched sample of 14 was selected

from the total sample of novices by closest pair-wise age match to the experts (Mage

= 37.4 years, SD = 10.1, range 25 – 61). Table 1 shows further comparisons between

the expert and novice groups. The proportion in graduate-level occupations was

similar for expert and novice groups, but the experts played more frequently, Mann-

Whitney U = 183.5, $p < .0005$, and their last game was more recent, U = 183.5, $p <$

.0005, than novices. The age at which they started to play did not differ significantly.

Table 1 near here

All participants had normal visual acuity, and wore their prescription glasses or contact lenses during the experiment if required. All the experts had an English Chess Federation (ECF) rating between 125 and 225 ($M = 164.4$, $SD = 24.5$). Using the international rating system, this is equivalent to between 1650 and 2450 ($M = 1965.4$, $SD = 195.8$). One of the experts had the status of grandmaster. None of the novices had an ECF or international rating. Participants were recruited by advertising on university websites and on the English Chess Federation website. All participants gave their informed consent, and the experimental protocol was approved by the Departmental Research Ethics Committee.

Materials

Chess ability test.

To estimate the level of expertise of the novice group, and to verify differences in expertise between the groups, a chess expert devised, specifically for this study, five chess problems of graded difficulty in which participants had to find the best possible move for White.

Detection task.

Unique chess positions ($N = 128$) on a 4×4 square minichessboard were presented for 0.5 s on a VDU monitor at 100 Hz frame rate. There was a 4 s interstimulus interval in which a blank screen at mean luminance appeared, together with a central fixation cross. We used 4×4 rather than 8×8 chessboards, and a brief exposure time, to minimize eye movements. The stimuli subtended $3° \times 3°$, at a viewing distance of 118 cm. Of the 128 chess positions in the stimulus set, 64 were simple (Figure 1 a, c), consisting of a white king, plus black bishop and knight, or white king, plus two black bishops; and 64 were more complex (Figure 1 b, d)

consisting of a white king, plus a black bishop, knight and two black pawns, or white

king, plus two black bishops and two black pawns.

Figure 1 near here.

Design

Table 2 illustrates the overall design of the study. Stimuli were divided into

four blocks of 150 trials representing four separate recognition tasks. It is an

important feature of the design of the experiment that although the task differed in

each block, the stimulus set used for each task/block was identical. The second

important feature of the design was that a response was required on only 1/5 of trials

(Go trials). Thus, in Block (a), "white king in check" was Go (response required) and

the response was withheld for "white king not in check." In Block (b), "black knight

present" was Go and "no black knight present" was Nogo. In Block (c), "white king in

check" was Nogo and "white king not in check" was Go. For block (d), "black knight

present" was Nogo and "no black knight present" was Go. Stimuli for the 120 Nogo

trials in each block were randomly sampled (with repetitions) from the 64 relevant

nontarget stimuli and the 30 Go trials were randomly sampled from the 64 relevant

target stimuli (repetitions allowed). Blocks were counterbalanced in order across

participants. There are asymmetries between target-present and target-absent searches

(Akyürek et al., 2010; Treisman & Gelade, 1986) and the design allowed both to be

studied. This design also ensured that for the majority of trials no button press was

required for a correct response, eliminating possible confounding effects on ERP of

response preparation, while identification of chess pieces and meaningful

configurations of pieces was no less required on Nogo than on Go trials. False

positive error trials (button press on Nogo) were excluded. Despite fewer valid trials, the Go trials met ERP data requirements, so a secondary analysis of Go trials is included.

Table 2 near here.

EEG Recording and Data Analysis

Participants wore a 32 channel Quik-cap with sintered ceramic Ag/AgCl electrodes filled with Quik Gel (Compumedics Neuromedical Supplies). Electrodes were located at the following 10/20 positions: O1, Oz, O2, P7, P3, Pz, P4, P8, TP7, CP3, CPz, CP4, TP8, T7, C3, Cz, C4, T8, FT7, FC3, FCz, FC4, FT8, F7, F3, Fz, F4, F8, AF1, and AF2. An average mastoid reference was used and vertical and horizontal EOG were also recorded. Impedances were < 10 KΩ. EEG was amplified at a gain of 1000 and bandpass $0.1 - 100$ Hz and digitized at 1000 Hz using a Synamps amplifier and Scan 4.2 acquisition and analysis software (Compumedics Neuroscan). The offline EEG time series was bandpass filtered at $0.1 - 30$ Hz, 24dB/octave, no phase shift, and blink artifacts were removed by a Spatial Filter procedure (Scan 4.2). The cleaned EEG time series was epoched from -100 to 1000 ms (0 ms = stimulus onset). Sweeps were baseline corrected (entire sweep), and those containing EEG amplitudes greater than ±75 μV were rejected. Average ERPs were obtained for all 8 conditions of interest (Table 2) for each participant. Prior to amplitude and latency measurements, or group averaging, all average ERPs were again baseline corrected to the pre stimulus interval (-100 to 0 ms). ERP amplitudes and latencies were detected in the individual average ERP data for each experimental condition by a peak detection algorithm (Scan 4.3) operating across all electrodes within specified time

windows: 90 – 120 ms for P1, 260 – 360 ms for N2, and 400 – 600 ms for P3. Data

were transferred to a matrix with a single row for each participant and a single column

for each combination of electrode and experimental condition. Regions of interest

were selected for statistical analysis (midline electrodes for N2 and P3; parietal

electrodes for P1) and amplitudes and latencies were analyzed using ANOVA.

Procedure

Participants signed a consent form and then filled in a short questionnaire on

brief demographic details and their experience of playing chess. Then the electrode

cap was fitted and the electrodes filled with gel: While the cap was stabilizing,

participants were given five trial chess problems, which were presented on a computer

screen, and their accuracy and overall time taken were recorded. Participants were

then seated in front of the stimulus screen and given a hand-held button box. After

impedance testing, a sample EEG was recorded, then the room lights were dimmed

and the experiment began. A brief practice trial was shown in order to explain the

general nature of the stimuli and the task, together with instructions to minimize

movement and blinks and maintain concentration during the experimental blocks. For

the experiment itself, different instructions were given at the start of each block: i.e.,

press the button (a) if the white king is in check; (b) if the white king is not in check;

(c) if there is a black knight present; and (d) if there is no black knight present. Each

block lasted 11 min with a 5 min break between each block. Participants were

required to respond to Go stimuli only, within the 4 s inter stimulus interval.

Results

Behavioral Results

Time taken to complete the chess ability test and the accuracy of the answers were recorded. The results of the test confirmed that the experts (M correct = 4.6, SD = .74; M time per item = 18.8 s, SD = 15.0 s) were superior to the novices (M correct = 2.6, SD = 2.9; M time per item = 41.0 s, SD = 23.4 s). These differences were significant: for accuracy, $t(26) = 6.03$, $p < .0005$; and for time per item, $t(26) = -2.99$, $p < .01$.

Table 3 shows accuracy on the ERP tasks for expert and novice players. The expert group showed close to 100% accuracy on both check and knight searches, whether on target present or target absent blocks. However, the novice groups were much more accurate on knight searches than check searches. Because the distribution of accuracy scores was not normal, nonparametric tests were used. Mann-Whitney U tests ($N_1 = 14$, $N_2 = 14$), Bonferroni corrected for multiple comparisons, confirmed that group differences arose on Go check, $U = 0.5$, $p < .005$, Go nocheck, $U = 19.5$, $p < .005$, Nogo nocheck, $U = 35$, $p < .05$ and Nogo noknight, $U = 32.5$, $p < .05$. There were thus significant group differences in accuracy on one out of four conditions involving a search for a black knight, and three out of four conditions involving a search for check.

Table 3 near here.

ERP Results

   Waveform and scalp distribution of ERP.

Figure 2a, 2b near here.

Figure 2a shows grand average ERPs for experts and age-matched novices from midline electrodes. The results are those from Nogo trials. For the check search, a negative peak was prominent in experts at around 300 ms and was correspondingly smaller in novices. The negativity of the experts' ERP compared to that of novices began earlier, around 240 ms on posterior electrodes. Also, early potentials P1 and N1 were visible on posterior electrodes, presumably concerned with perceptual processing, and these appeared similar in experts and novices. There was also a P3 peaking at around 500 ms that was larger on frontal-central electrodes in experts. ERPs for the nocheck condition in Figure 2a are similar in form to the check results.

The second column of Figure 2a shows ERPs for the knight search on Nogo trials. There was a P3 wave peaking at around 500 ms that was larger in experts on frontal-central electrodes. Again, on posterior electrodes, experts' ERPs were more negative on the knight search than novices' from around 240 ms (N2). ERPs for the noknight condition in Figure 2a are similar in form to the knight condition.

Figure 2b shows the supplementary data from Go trials, recorded with one quarter of the number of trials per participant (see Table 2). The data preserve, with some variations, the general form of the ERP waveforms and expert-novice differences seen in Figure 2a.

Figure 3 shows 2D scalp maps of ERP mean amplitudes across all electrodes. Since latencies around 300 ms and 500 ms appear to be crucial for expert-novice differences in chess ERPs, we compared the 2D mean amplitude maps at 275 – 325 ms and at 450 – 550 ms to explore the scalp distribution of N2 and P3 in experts and novices in all eight experimental conditions. From these maps some differences emerged.

For novices, negativity at 275 – 325 ms was restricted to frontal regions around Fz and FCz, and there was marked P2-like occipital-parietal positivity, whereas for experts, there were two N2 foci; near FCz and near CPz and the negativity was deeper. Secondly, for experts, N2 was larger in check-related than the knight-related conditions, whereas for novices the response to check-related and knight-related conditions was similar. From this description, we can see that the N2 wave seems to correlate with expertise in the check search. It was large in experts and small in novices, particularly on posterior electrodes. P3, measured at 450 – 550 ms, also differed between experts and novices. With check targets, P3 was at a maximum on frontal electrodes in experts and on parietal electrodes in novices. With knight targets, the experts' P3 encompassed both frontal and parietal loci, whereas in novices, P3 showed parietal maxima. To test the significance of these differences, P1, N2 and P3 amplitudes were selected for further statistical analysis.

Figure 3 near here.

ANOVA analysis.

Table 4 summarizes the results for six ANOVA analyses. Separate analyses were carried out for three different dependent variables, represented by the columns in Table 4, namely, the P1, N2, and P3 amplitudes measured at an appropriate sample of scalp locations. The main analyses relate to the Nogo trials (see Table 2). A separate, supplementary analysis was made for the Go conditions, in which the signal/noise ratios were less than half those of Nogo trials. The overall ANOVA design consisted of 2 levels of Search Type (target present, target absent) × 2 levels of Target Type (check, knight) × 5 levels of Electrode (P7, P3, Pz, P4, and P8 for P1, or Fz, FCz, Cz,

CPz, and Pz for N2 and P3) × 2 levels of Group (expert, age-matched novice). The

dependent variable for P1 was the maximum voltage relative to baseline in the latency

range 90 – 140 ms. Electrodes chosen on the basis of the observed distribution of the

P1 component were P7, P3, Pz, P4, and P8. The dependent variable for N2 was the

minimum voltage relative to baseline in the latency range 260 – 360 ms. The

electrodes chosen for ANOVA were those on the midline from Fz to Pz (see Figure

3). The dependent variable for P3 was positive peak amplitude in the 400 – 600 ms

range on electrodes Pz through Fz.

Note also that all the three-way and four-way interactions were nonsignificant.

Greenhouse-Geisser correction to degrees of freedom was used for all tests involving

comparisons across electrode positions (epsilon values were 0.38 – 0.48), and

Levene's test was nonsignificant for all ERP variables, indicating that equal variances

may be assumed. Post hoc tests on interactions between group (expert, novice) and

within-participant factors were based on the factor MS for each participant group, and

the error MS for the interaction term, and were Bonferroni-corrected for multiple

comparisons (Weinberg & Abramowitz, 2008). The presentation of results is

organized around the four hypotheses stated in the Introduction of this paper.

Table 4 near here.

Hypothesis 1.

The first hypothesis proposed expert-novice differences in ERPs in relation to

the chess tasks employed in this study. There were no significant main effects of

group (expert, matched novice) in any of the six ANOVAs conducted.

As Table 4 shows, there were significant interactions between group and electrode on N2 and P3 peaks, indicating a difference in their scalp distribution for experts and novices and supporting Hypothesis 1. Post hoc trend analysis showed a significant quadratic trend in experts with greatest negativity of N2 at Cz and least negativity at Fz, $F(1, 13) = 13.45$, $p < .01$. For novices, the linear trend was significant, $F(1, 13) = 7.39$, $p < .05$, and N2 was increasingly more negative on anterior electrodes. Furthermore, there was a significant interaction between group and electrode on P3 in Nogo trials supporting Hypothesis 1. Polynomial trend analysis showed a significant linear anterior-posterior gradient of P3 in novices, with amplitude increasing to a maximum on Pz, $F(1, 13) = 6.95$, $p < .05$, but experts showed a more uniform distribution of P3 across the midline electrodes with no significant trend.

Table 4 shows a significant Group × Electrode interaction for N2 on Go trials. Trends in expert and novice data were not however separately significant after the Bonferroni correction. ANOVA results for P3 on Go trials were similar to those from Nogo trials, but the P3 peak was greater in amplitude. This would be expected from detection of the less probable stimulus. To summarize, experts and novices differ in the anterior-posterior distribution of N2 and P3 to chess stimuli across midline electrodes, as shown by ANOVA and also indicated in Figure 3.

Hypothesis 2.

According to the second hypothesis expert-novice differences are predicted to be larger for tasks that involve recognition of a functional and spatial relationship between objects, i.e., "is the white king in check?", and smaller for identification of a particular object, i.e., "is there a black knight on the board?" The key comparison for

ANOVA is thus the interaction between group (expert, age-matched novice) and target type (knight, check).

Table 4 shows the results for the Group x Target Type interaction. No significant effect was found on P1. On N2 for Nogo trials, there was a significant Group × Target Type interaction, with experts showing a more negative N2 on check (M = -6.7) compared with knight (M = -4.3) searches, whereas age-matched novices showed similar amplitude for check (M = -2.6) and knight (M = -3.0) searches. To understand how this significant interaction arises, a post hoc ANOVA procedure (Weinberg & Abramowitz, 2008) was used to examine the results by group. It was found that experts showed significant differences according to target type, after Bonferroni correction. $F(1, 13) = 19.83$, $p < .005$, unlike novices, $F(1, 13) = .128$, ns. Thus, in confirmation of Hypothesis 2, there is substantial differentiation of ERPs according to check versus knight tasks, but only for experts. On N2 for Go trials, there was a nonsignificant trend in the predicted direction ($p = .07$), with larger expert-novice differences on check tasks than on knight tasks. The Group × Target Type interaction for P3 showed a nonsignificant trend in the predicted direction on Nogo trials ($p = .07$) and was significant for the Go trials. Post hoc ANOVA for Go trials showed a significant difference in P3 amplitude for target type in experts, $F(1, 13) = 14.5$, $p < .005$, but not in novices, $F(1, 13) = .01$, $ns.$

Hypothesis 3.

The third hypothesis proposed that there would be differences in ERP latency for experts and novices, but ANOVA on P1, N2, and P3 peak latencies revealed no expert-novice differences. Thus, Hypothesis 3 was not confirmed.

Hypothesis 4.

The fourth (exploratory) hypothesis proposed that there are ERP differences for experts versus novices in target-present (e.g., "respond if the king is in check," "respond if there is a black knight") and target-absent (e.g., "respond if the king is not in check," "respond if there is no black knight") searches. This would be confirmed if ANOVA showed significant interactions between search type and group.

As Table 4 shows, on P1 in Nogo trials, this interaction was significant and the post hoc ANOVA showed that for age-matched novices, there was larger P1 amplitude when the response was withheld for an absent target, $F(1, 13) = 18.41$, $p < .005$, but no significant difference due to search type in the expert data, $F(1, 13) = 2.43$, *ns.* There was no significant Search Type × Group interaction on N2, but for P3, the Search Type × Group interaction was again significant both on Go and on Nogo. Separate post hoc analyses for Experts and Novices on Nogo trials showed no significant differences due to search type. On Go trials, experts showed a larger P3 for target present than for target absent searches, $F(1, 13) = 14.6$, $p < .005$, but for novices the difference was not significant, $F(1,13) = .14$, *ns.* This gives some support for Hypothesis 4.

Other effects.

A number of significant results not involving expert-novice differences have been recorded in Table 4. Principally, the main effect of target type was significant, for N2 and P3 (Nogo trials) and for P1 and P3 (Go trials) and the main effect of search type was significant for P1 (Nogo), N2 (Go), and P3 (Go). Target Type × Electrode was also significant overall for N2 (Nogo) and Target Type × Search Type was significant overall for N2 (Nogo) and P3 (Go). These results suggest that there are common effects of experimental conditions on ERPs in both subject groups, in

addition to differential effects. As noted above, three-way and four-way interactions were not significant.

   Differential effects of expertise on check- and knight-related tasks.

   <u>Figure 4a, 4b near here</u>

   Figure 4a gives a graphical representation of how the Group × Target Type interaction predicted in Hypothesis 2 evolves over time in the ERP waveform. Figure 4a shows a within-group comparison of check-related (check + nocheck) and knight-related (knight + noknight) ERPs.

   Both check-related and knight-related tasks require the visual identification of chess pieces, but the check tasks additionally require the analysis of the relative positions of pieces on the board in terms of the potential moves of those pieces. Check-related and knight-related blocks contained closely-matched stimulus sets, so it could be expected that early stages of visual analysis, reflected in early ERP components, would be similar. It can be seen in Figure 4a that when the within-group check-related and knight-related ERPs are superimposed, the early parts of the traces coincide.

   The divergence between the check-related and knight-related ERPs is much greater in experts than novices, and begins in the N2 range, extending into the range of P3. The maximum difference between the check and knight ERPs occurs around 400 ms, and the negativity is more prolonged in the check condition.

   Figure 4a also shows statistical parametric maps (*t* scores) across all EEG electrodes for the difference between check-related and knight-related ERPs, centered on the 300 ms (N2) and 400 ms (P3) maximum. These plots are based on average

amplitudes over a 100 ms time range rather than peak amplitudes. Paired-samples *t*-tests with Bonferroni correction across electrode positions showed significant effects in experts over frontal, central, and parietal cortex on Nogo trials (Figure 4a). Significant effects were found also for experts on Go trials (Figure 4b) notwithstanding the lower signal/noise ratio of Go data (see Methods). In novices, a check – knight mean difference of similar shape and extent to that in experts did not reach statistical significance (Figure 4a). The scalp distribution and time course of the differences between check and knight ERPs would be consistent with an enhanced N400-like process in check-related tasks in experts.

Discussion

This study analyzed the underlying neural events taking place in chess players when they make simple judgments. Hypothesis 1 predicted expert-novice amplitude differences in ERP on chess tasks. These expert-novice differences in ERPs to chess tasks emerged over posterior cortex at a latency of around 240 ms and persisted until 400 – 700 ms, and plausibly they represent enhanced processing of attended chess stimuli by experts. Despite the wide age range in the sample, the results reported here cannot be attributed to age-related effects in attention, as reflected in ERP components (Kok, 2000), because the novice control group was matched in age to the expert group.

Early components

In previous studies, it was found that semantic knowledge facilitated perception and reduced P1 and N1 amplitudes (Abdel Rahman & Sommer, 2008; Curran et al., 2009), and this was explained as increased efficiency of neural

processing. In the present study, P1 amplitude on Go trials was significantly greater overall in check-related than in knight-related tasks, which is consistent with a neural efficiency argument in that the top-down information for check targets is more ambiguous than that for knight targets; thus, perception in the knight task is more facilitated. However, there was no corresponding expert-novice difference in P1.

Posterior N2

In experts, posterior N2 was present on knight tasks but larger in check tasks but in novices, posterior N2 was reduced or absent for both target types The fact that the expert-novice differences in N2 were stronger in the checking condition is consistent with the proposal of a functional brain reorganization in expertise domains involving working memory: with high levels of expertise, the presence of memory structures such as templates makes it possible to use parts of long-term memory as virtual working memory (Guida, Gobet, Tardieu, & Nicolas, 2012). It is possible that individual differences in cognition unrelated to chess contribute to this result, but the groups were similar in educational level. On the other hand, the groups differed substantially on the frequency and recency of chess playing. Furthermore, there is substantial evidence for domain-specific expertise in object recognition (Gauthier et al., 2009; Hertzmann & Curran, 2011; Tanaka & Curran, 2001) including chess (Bilalić et al., 2010). Consistent with previous fMRI and behavioral data (Bilalić et al., 2011), is the result that expert-novice differences in N2 were found both for chess-related functional targets (check and nocheck) and object recognition targets (knight and noknight).

Experts showed a larger N2 than novices particularly with check targets. Two possible interpretations of this difference will be considered, one based on a discrete

posterior N2 related to visual attention, and one based on an N400-like effect and memory.

The parietal N2 associated with visual attention and visual search corresponds with "selection negativity" (SN: Hillyard & Anllo-Vento, 1998). The significant Group × Target Type interaction would imply that in experts, there is a greater engagement of posterior cortical mechanisms in visual search, particularly for the check target. SN is nonlateralized and is associated with search for object qualities such as shape or color, rather than for the occurrence of targets at particular locations in the case of the lateralized N2pc; and scalp topographies of SN may differ for different types of qualitative feature (Hillyard & Annlo-Vento, 1998). This is consistent with the view that the posterior N2 in the present study is a SN since it depends on attention to a particular quality rather than a particular spatial location (object shape and color in the case of knights, and a functional spatial relationship of objects in the case of checks), as well as being nonlateralized.

The second interpretation relates to the representation of knowledge in memory. The involvement of memory processes in the check tasks in experts is suggested by the long duration of the N2 negativity (Figures 2, 4). Long-lasting N2 components related to working memory can be elicited when the visual information in a brief presentation requires in-depth processing. These components include N400, which was originally elicited in response to semantically anomalous sentences (Kutas & Hillyard, 1980) but also has been implicated in old/new picture recognition tasks (Friedman, 1990, Rugg & Curran, 2007). The N400 is sensitive to the depth of semantic knowledge about a perceived object: it is greater for items that are well-known than for items about which the observer has minimal knowledge, and shows effects of perceptual expertise (Abdel Rahman & Sommer, 2008; Curran, Gibson,

Horne, Young, & Bozell, 2009; Hertzmann & Curran, 2011; Riby & Orme, 2013). This corresponds well with the pattern of results in the present study. Firstly, experts show a greater N400-like effect on posterior electrodes than novices (Expertise × Electrode interaction). This is in accordance with the idea that experts possess a greater knowledge base of chessboard configurations.

Secondly, experts show a larger N400-like response in check compared to knight conditions. The dependence of the check task on accessing a knowledge base of functional spatial relationships may be responsible for the large N400-like response. However, for the knight tasks, there is a smaller N400-like effect. This result is consistent with the idea that for the expert, the check task is more meaningful, that is, more closely connected with accessing stored knowledge (Riby & Orme, 2013). We can conclude that the larger posterior N2 in experts in the check conditions is related to a clearer discrimination of check from nocheck configurations, assisted by memory for configurations. The implication would be that for chess experts, functional configurations of pieces on a chess board have become established features in a feature space, and that cortical machinery is devoted to representing that feature space, but not so in novices.

Frontal-central N2

The frontal-central N2 is present in both experts and novices with both types of target (Figures 2and 3). Folstein and van Petten (2008) identify at least two circumstances in which a frontal-central N2 is seen: firstly, a mismatch between a stimulus and a target, and secondly, cognitive control. N2 and P3 components have been linked to response inhibition in Go/Nogo paradigms (Fox et al., 2000), and to inefficient visual search (see Li, Gratton, Yao, & Knight, 2010, Figure 2), that is, search requiring cognitive effort. Cognitive control may have been necessary in all

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experimental conditions because of the presence of distractors (target-irrelevant chess pieces) which decrease the efficiency of search. Also, the inclusion of Nogo trials and target-absent searches in the block design is likely to require inhibitory control of responses. Overall, the evidence suggests that a frontal, cognitive control N2 operates in both experts and novices.

P3a and P3b

The scalp distribution of P3 differs between experts and novices. Moreover parietal P3 (presumptive P3b) was present in novices on both check and knight-related searches, whereas in experts, P3 was fronto-central (presumptive P3a) in check searches, and both frontal and parietal (presumptive P3a + P3b) in knight-related searches (Figure 3).

The frontal P3a is associated with attention, and the parietal P3b is associated with memory processes and context updating (Polich, 2007). On the check tasks, experts had the largest P3 over frontal electrodes, whereas on knight tasks, their P3 encompassed both frontal and parietal electrodes. However, novices had a parietal P3b rather than frontal P3a on both check and knight tasks (see Figure 3). The presence of P3a in experts and its low amplitude in novices may indicate that experts engage visual selective attention more effectively in the task. The larger P3 amplitudes on knight (and noknight) relative to check (and nocheck) blocks are consistent with an inhibition based allocation of attention resources (Polich, 2007). This suggests that P3 amplitudes should decrease as processing demands increase; thus, the greater processing demands of the check-related conditions effectively reduce the P3 amplitude relative to the knight-related conditions. The same account would predict larger P3 amplitudes in experts on knight-related searches, as was found. The largest amplitude P3 are found on Go trials, and this is also to be expected,

since P3 amplitude varies inversely with stimulus probability and Go stimuli

represented a minority of trials.

ERP peak latencies

There were no significant expert-novice differences in N2 or P3 peak

latencies, contrary to Hypothesis 3; note that, because the N2 and P3 amplitudes are

greater in experts, it follows that the time taken to reach a given threshold voltage is

shorter. It is not known whether ERP amplitude correlates with behavioral reaction

time in chess recognition tasks, but in the present experiments, experts identified

functional relationships between chess objects in very brief stimulus presentations.

No more than 500 ms was needed to register a check configuration with near perfect

accuracy. Differences between expert and novice ERP responses occurred at least as

early as the onset of N2 (Figure 2). Thus, 240 ms after first seeing a chess

configuration, an expert's brain is already engaged in object identification and

functional analysis of the chess position.

Target-present and target-absent searches

In support of the fourth (exploratory, nondirectional) hypothesis, proposing

expert-novice differences between target-present and target-absent searches,

significant interactions were found between expertise and search type on P1 (Nogo)

and P3 (Nogo and Go) amplitudes. The pattern of results is complex. P3 data showed

larger amplitudes only for experts for target-present searches on Go trials, but the

effect on P1 appears only on the novice data, and target-absent searches gave larger

amplitudes. Target-present and target-absent searches clearly have different ERP

effects but these are sensitive to other stimulus factors (Akyürek, et al. 2010).

Behavioral results

There is a partial disconnection between behavioral results and the ERP results, in that the accuracy of novices on knight and check target searches is different but the ERPs are similar, whereas for the experts, behavioral performance is similar, and their ERPs are different. In the case of experts, detection accuracy on both targets was near ceiling, so the behavioral accuracy measure was insensitive. For novices, template theory predicts that the depth of processing in the check task is less than that of experts, and therefore more similar to that in the knight search; this would explain why novices have more similar ERPs to check and knight targets. Also, the design of the tasks was based on the assumption that there is a common element in both tasks, namely, that a piece (black knight, white king) must be identified; but there is an additional element in the check tasks, namely, the identification of the functional spatial relationship between the king and other pieces.

Overall conclusions

The observed differences in the scalp distribution of N2 and P3 suggest that the organization of the brain for chess tasks is qualitatively different in experts and novices, which is a view consistent with fMRI evidence (Bilalić et al., 2011). Behavioral evidence supports the conclusion that there is a difference in the way that expert and novice chess players process functional configurations in brief exposures.

Overall, the present results are consistent with template theory (Gobet & Simon, 1996). Thus, "king in check" would be, for experts but not for novices, a template comprising multiple instances, which could be compared rapidly with current perceptual input. Application of a template for "king in check" would provide a basis for attentive search and the extended N400-like time course of the N2 in experts' check searches suggests the application of a rich memory representation including multiple ways that the king could be in or out of check from the identified

pieces. However, if the representation in memory of "king in check" is weak or ambiguous in novices, it will not be possible to make thorough comparisons with current perceptual input, and search may be based on a very simplified template not very different in complexity from that employed in the knight identification search.

The ERP data contradict a simple "neural efficiency" account in which ERP amplitude reflects task difficulty, as this would predict that novices show greater ERP amplitudes for all components especially in the more difficult (check and nocheck target) tasks. However, the P3 results, for example the large amplitude of P3 for knight targets in experts, can support a "neural efficiency" argument if P3 is seen as primarily inhibitory, with P3a reflecting the selective efficiency of visual attention, and P3b modulating the balance between stimulus detection and working memory (Polich, 2007). On the other hand, the large amplitude N400-like effect in experts' processing of check configurations is consistent with recruitment of a more widely distributed neural network corresponding to the much richer structure of the templates that they employ. Furthermore, it was shown here that expert-novice ERP differences occur as little as 240 ms after stimulus onset. Thus, chess experts can perceive important functional configurations of pieces in 0.5 s exposures with near 100% accuracy, and corresponding ERP evidence suggests that they are able to access complex neural structures when the task demands it.

References

Abdel Rahman, R., & Sommer, W. (2008). Seeing what we know and understand: how knowledge shapes perception. *Psychonomic Bulletin and Review, 15,* 1055-1063. doi: 10.3758/PBR.15.6.1055

Akyürek, E.G., Dinkelbach, A., Schubö, A., & Müller, H.J. (2010). Electrophysiological correlates of detecting a visual target and detecting its absence: The role of feature dimensions. *Neuropsychologia, 48,* 3365-3370. doi: 10.1016/j.neuropsychologia.2010.07.005

Bilalić, M., Kiesel, A., Pohl, C., Erb, M., & Grodd, W. (2011). It takes two – Skilled recognition of objects engages lateral areas of both hemispheres. *PLoS ONE, 6,* e16202. doi: 10.1371/journal.pone.0016202

Bilalić, M., Langner, R., Erb, M., & Grodd, W. (2010). Mechanisms and neural basis of object and pattern recognition: A study with chess experts. *Journal of Experimental Psychology: General, 139,* 728-742. doi: 10.1037/a0020756

Bilalić, M., Turella, L., Campitelli, G., Erb, M., & Grodd, W. (2012). Expertise modulates the neural basis of context dependent recognition of objects and their relations. *Human Brain Mapping, 33,* 2728-2740. doi: 10.1002/hbm.21396

Campitelli, G., Gobet, F., Head, K., Buckley, M., & Parker, A. (2007). Brain localization of memory chunks in chess players. *International Journal of Neuroscience, 117,* 1641-1659. doi:10.1080/00207450601041955

Campitelli, G., Parker, A., Head, K., & Gobet, F. (2008). Left lateralization in autobiographical memory: An fMRI study using the expert archival paradigm. *International Journal of Neuroscience, 118,* 191-209. doi: 10.1080/00207450701668053

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology, 4,*
       55-81. doi: 10.1016/0010-0285(73)90004-2

Chassy, P., & Gobet, F. (2011). Measuring chess experts' single-use sequence
       knowledge using departure from 'theoretical' openings: An archival study.
       PLoS ONE, 6, e26692. doi: 10.1371/journal.pone.0026692

Curran, T., Gibson, L., Horne, J.H., Young, B., & Bozell, A.P. (2009). Expert image
       analysts show enhanced visual processing in change detection. *Psychonomic
       Bulletin and Review, 16,* 390-397. doi: 10.3758/PBR.16.2.390

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch
       on the N2 component of the ERP: A review. *Psychophysiology, 45,* 157-170.
       doi: 10.1111/j.1469-8986.2007.00602.x

Fox, A.M., Michie, P.T., Wynne, C.D.L., & Maybery, M.T. (2000). ERP correlates of
       response inhibition to elemental and configural stimuli in a negative patterning
       task. *Clinical Neurophysiology, 111,* 1045-1053. doi: 10.1016/S1388-
       2457(00)00257-1

Friedman, D. (1990). Cognitive event-related potential components during continuous
       recognition memory for pictures. *Psychophysiology, 27,* 136-149. doi:
       10.1111/j.1469-8986.1990.tb00365.x

Gauthier, I., Tarr, M. J., & Bub, D. (2009). *Perceptual expertise: Bridging brain and
       behavior.* New York: OUP.

Gibson, J. J., & Gibson, E. J. (1955). Perceptual learning: Differentiation or
       enrichment? *Psychological Review, 62*, 32-41. doi: 10.1037/h0048826

Gobet, F., & Lane, P. C. R. (2010). The CHREST architecture of cognition: The role
       of perception in general intelligence. In Baum, E., Hutter, M., & Kitzelmann,

E. (Eds), *Proceedings of the Third Conference on Artificial General Intelligence.* (pp. 7-12). Amsterdam: Atlantis Press.

Gobet, F., Lane, P. C. R., Croker, S., Cheng, P. C-H., Jones, G., Oliver, I., & Pine, J. M. (2001). Chunking mechanisms in human learning. *Trends in Cognitive Sciences, 5,* 236-243. doi: 10.1016/S1364-6613(00)01662-4

Gobet, F., & Simon, H.A. (1996). Templates in chess memory: A mechanism for recalling several boards. *Cognitive Psychology, 31,* 1-40. doi: 10.1006/cogp.1996.0011

Gobet, F., & Simon, H.A. (2000). Five seconds or sixty? Presentation time in expert memory. *Cognitive Science, 34,* 651-682. doi: 10.1207/s15516709cog2404_4

Gobet, F., & Waters, A. J. (2003). The role of constraints in expert memory. *Journal of Experimental Psychology*: *Learning, Memory & Cognition, 29,* 1082–1094. doi: 10.1037/0278-7393.29.6.1082

de Groot, A. D. (1965). *Thought and choice in chess*. The Hague: Mouton Publishers.

de Groot, A., & Gobet, F. (1996). *Perception and memory in chess. Heuristics of the professional eye.* Assen: Van Gorcum.

Guida, A., Gobet, F., Tardieu, H., & Nicolas, S. (2012). How chunks, retrieval structures and templates offer a cognitive explanation for neuroimaging data on expertise acquisition: A two-stage framework. *Brain and Cognition, 79,* 221-244. doi:10.1016/j.bandc.2012.01.010

Herzmann, G., & Curran, T. (2011). Experts' memory: An ERP study of perceptual expertise effects on encoding and recognition. *Memory and Cognition, 39*, 412-432. doi: 10.3758/s13421-010-0036-1

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Hillyard, S.A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study

    of visual selective attention. *Proceedings of the National Academy of Sciences*

    of the United States of America, 95, 781-787. doi: 10.1073/pnas.95.3.781

Kok, A. (2000). Age-related changes in involuntary and voluntary attention as

    reflected in components of the event-related potential. *Biological Psychology,*

    54, 107-143. doi: 10.1016/S0301-0511(00)00054-5

Kutas, M., & Hillyard, S.A. (1980). Reading senseless sentences: Brain potentials

    reflect semantic incongruity. *Science, 207*, 203-205. doi:

    10.1126/science.7350657

Li, L., Gratton, C., Yao, D., & Knight, R.T. (2010). Role of frontal and parietal

    cortices in the control of bottom-up and top-down attention in humans. *Brain*

    Research, *1344*, 173-184. doi: 10.1016/j.brainres.2010.05.016

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical*

    Neurophysiology, 118, 2128-2148. doi: 10.1016/j.clinph.2007.04.019

Riby, L.M., & Orme, E. (2013) A familiar pattern? Semantic memory contributes to

    the enhancement of visuo-spatial memories. *Brain and Cognition, 81,* 215-

    222. doi: 10.1016/j.bandc.2012.10.011

Rugg, M., & Curran, T. (2007). Event-related potentials and recognition memory.

    Trends in Cognitive Sciences, 11, 251-257. doi: 10.1016/j.tics.2007.04.004

Tanaka, J. W., & Curran, T. (2001). A neural basis for expert object recognition.

    Psychological Science, 12, 43-47. doi: 10.1111/1467-9280.00308

Treisman, A., & Gelade, G.A. (1980). A feature-integration theory of attention.

    Cognitive Psychology, 12, 96-136. doi:10.1016/0010-0285(80)90005-5

Waters, A. J., & Gobet, F. (2008). Mental imagery and chunks: Empirical and

computational findings. *Memory & Cognition, 36,* 505-517. doi:

10.3758/MC.36.3.505

Weinberg, S.L., & Abramowitz, S.K., (2008) *Statistics using SPSS: An integrative

approach.* (2nd ed.), New York: Cambridge University Press.

Woodman, G.F., & Luck, S.J. (2003). Serial deployment of attention during visual

search. *Journal of Experimental Psychology: Human Perception and

Performance, 29,* 121-138. doi: 10.3758/MC.36.3.505

Wykowska, A., & Schubö, A. (2009). On the temporal relation of top-down and

bottom-up mechanisms during guidance of attention. *Journal of Cognitive

Neuroscience, 22,* 640-654. doi: 10.1162/jocn.2009.21222

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	Graduate or professional	Non-graduate	Median frequency of play	Median last game	years since starting
Experts	9	5	daily	yesterday	$M = 35.7$ $SD = 11.7$
Age-matched novices	10	4	1/month – 1/year	3-6 months ago	$M = 28.1$ $SD = 10.8$

	Block a 150 trials	Block b 150 trials	Block c 150 trials	Block d 150 trials
Search target	check	knight	nocheck	noknight
Nogo stimulus 4/5	White king not in check	No black knight present	White king in check	Black knight present
Go stimulus 1/5	White king in check	Black knight present	White king not in check	No black knight present

Nogo		check	knight	nocheck	noknight
expert	*M*	97.4	99.8	94.7	99.7
	SD	1.4	0.5	6.4	0.5
novice	*M*	80.2	95.9	82.3	96.3
	SD	18.4	10.7	14.0	6.6

Go		check	knight	nocheck	noknight
expert	*M*	94.2	100.0	95.0	97.2
	SD	9.6	0.0	7.9	5.2
novice	*M*	39.2	97.4	61.1	92.7
	SD	18.4	7.0	25.2	13.7

NoGo trials	P1		N2		P3		hypothesis
	F	$_p\eta^2$	*F*	$_p\eta^2$	*F*	$_p\eta^2$	
Group (1,26)	-	-	-	-	-	-	
Target type (1,26)	-	-	11.6***	.31	8.9**	.26	
Search type (1,26)	6.3**	.19	-	-	-	-	
Electrode (4,104)	-	-	-	-	-	-	
GxT (1,26)	-	-	8.4**	.24	-	-	2
GxS (1,26)	12.7***	.33	-	-	4.6*	.15	4
GxE (4,104)	-	-	7.6**	.23	3.6*	.12	1
TxS (1,26)	-	-	6.1*	-	-	-	
TxE (4,104)	-	-	3.7*	.12	-	-	
SxE (4,104)	-	-	-	-	-	-	
Three and four way interactions	-	-	-	-	-	-	

Go trials	P1		N2		P3		hypothesis
	F	$_p\eta^2$	*F*	$_p\eta^2$	*F*	$_p\eta^2$	
Group (1,26)	-	-	-	-	-	-	
Target type (1,26)	13.0***	.33	-	-	11.1***	.30	
Search type (1,26)	-	-	10.0***	.28	6.0*	.19	
Electrode (4,104)	-	-	-	-	-	-	
GxT (1,26)	-	-	-	-	11.0***	.30	2
GxS (1,26)	-	-	-	-	8.8**	.25	4
GxE (4,104)	-	-	6.0**	.19	3.6*	.12	1
TxS (1,26)	-	-	-	-	7.5*	-	
TxE (4,104)	-	-	-	-	-	-	
SxE (4,104)	3.5*	.12	-	-	-	-	
Three and four way interactions	-	-	-	-	-	-	

*$p<0.05$, **$p<0.01$, ***$p<0.005$.

a

b

c

d

Go   check   knight   nocheck   noknight

Fz

FCz

Cz

CPz

Pz

μV +5 / -5

0   500   Time ms   0   500   Time ms   0   500   Time ms   0   500   Time ms

experts ——— novices

Check – related _____

Knight – related _____

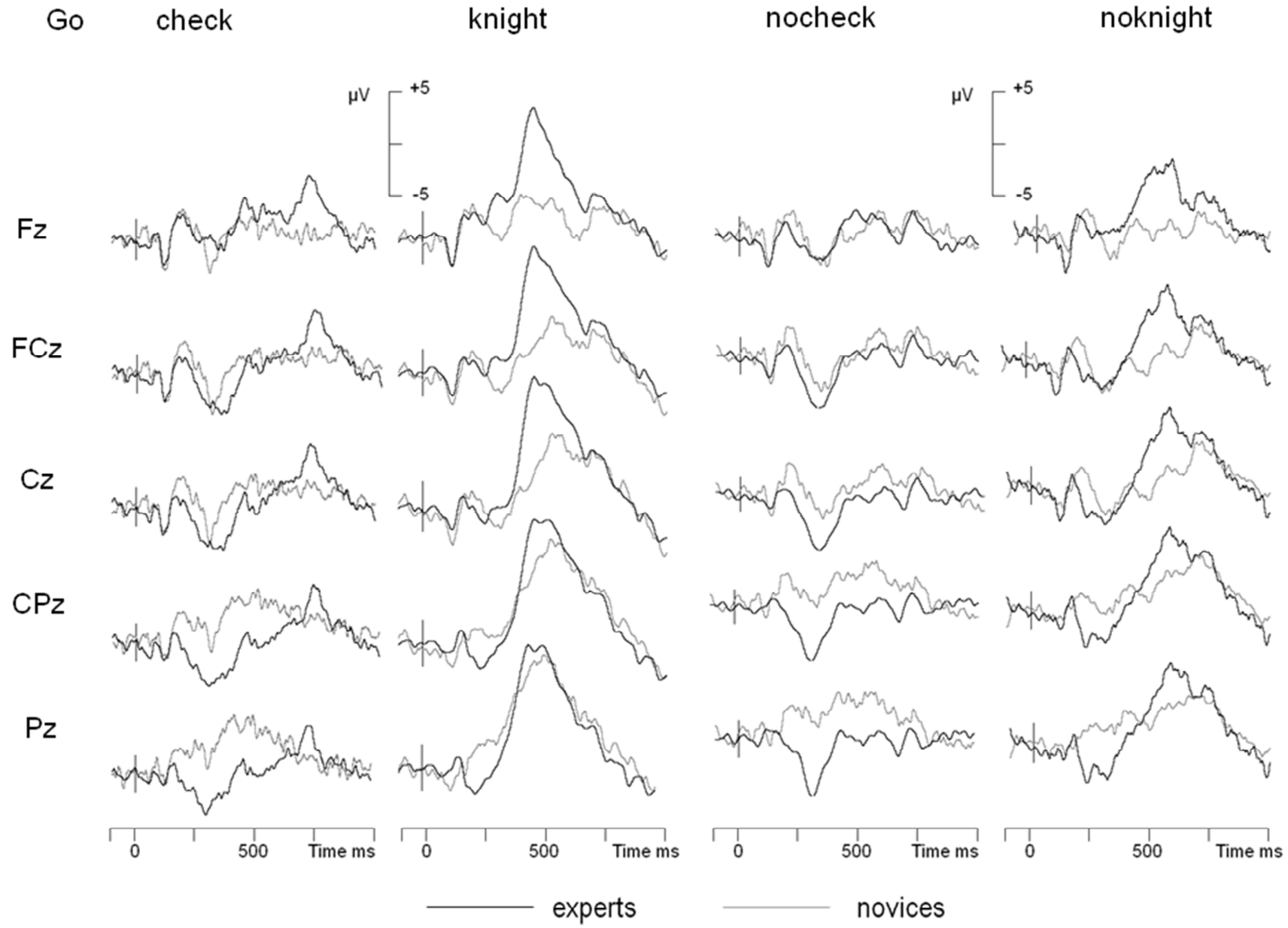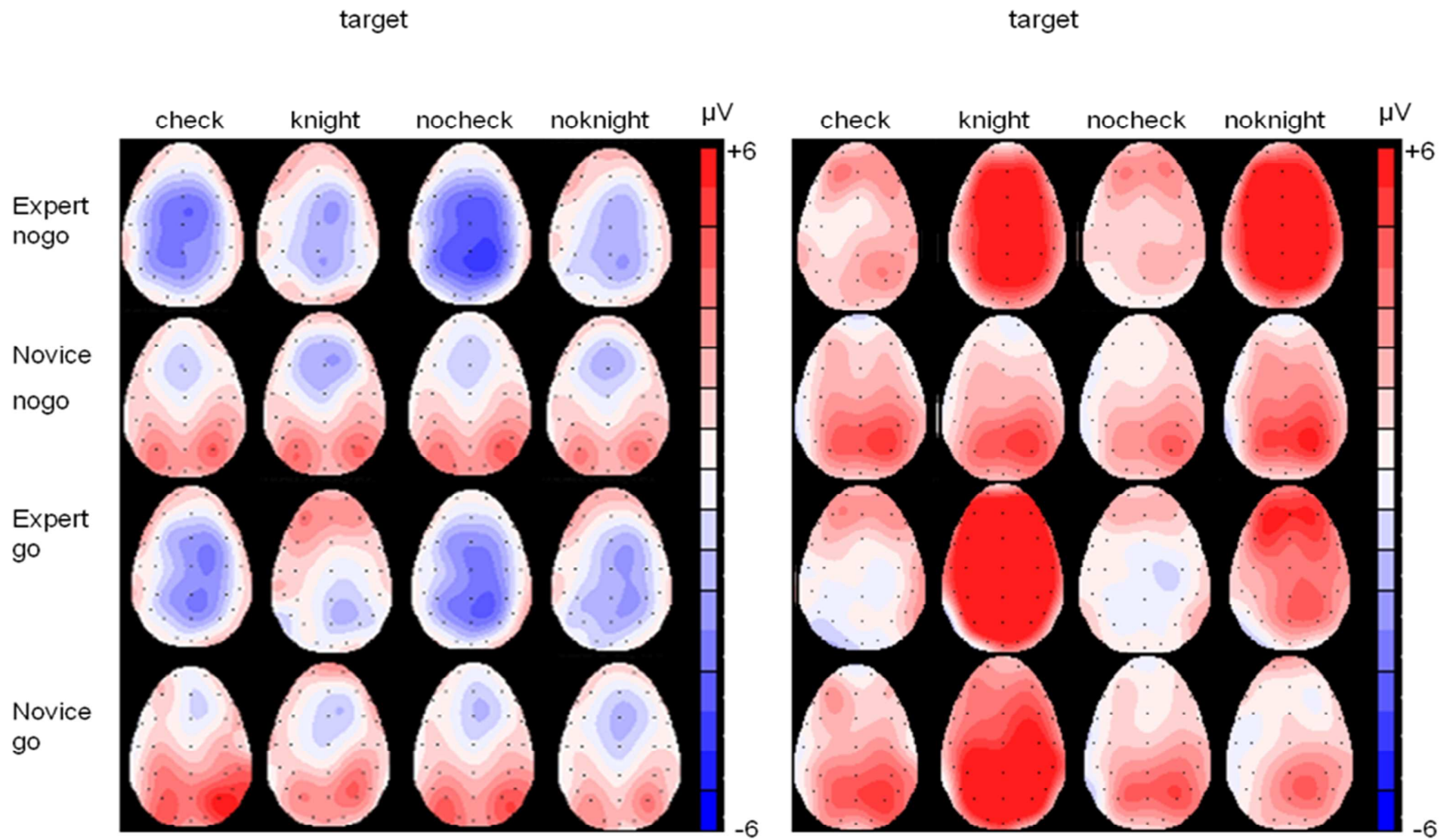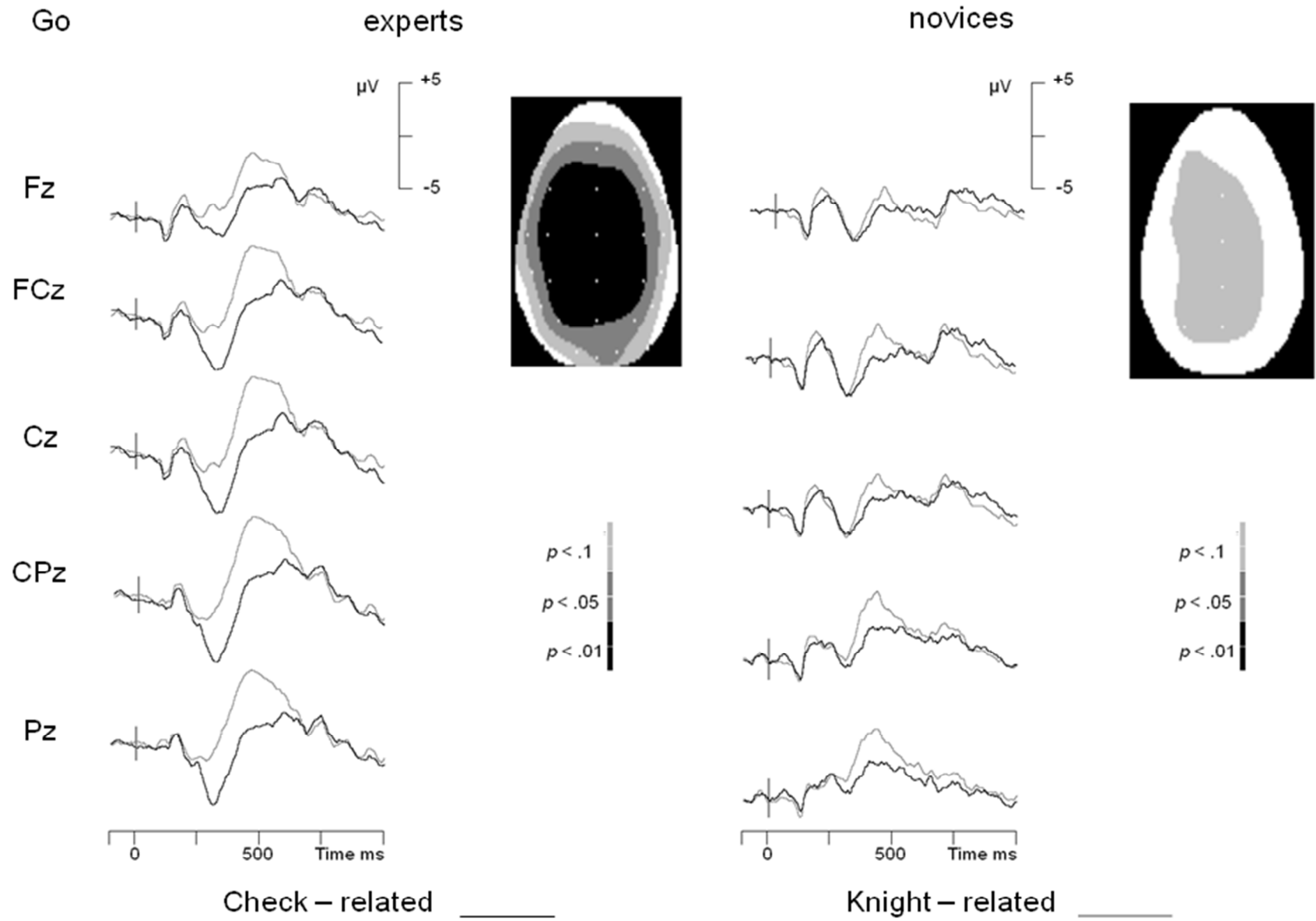Go   experts   novices

Fz

FCz

Cz

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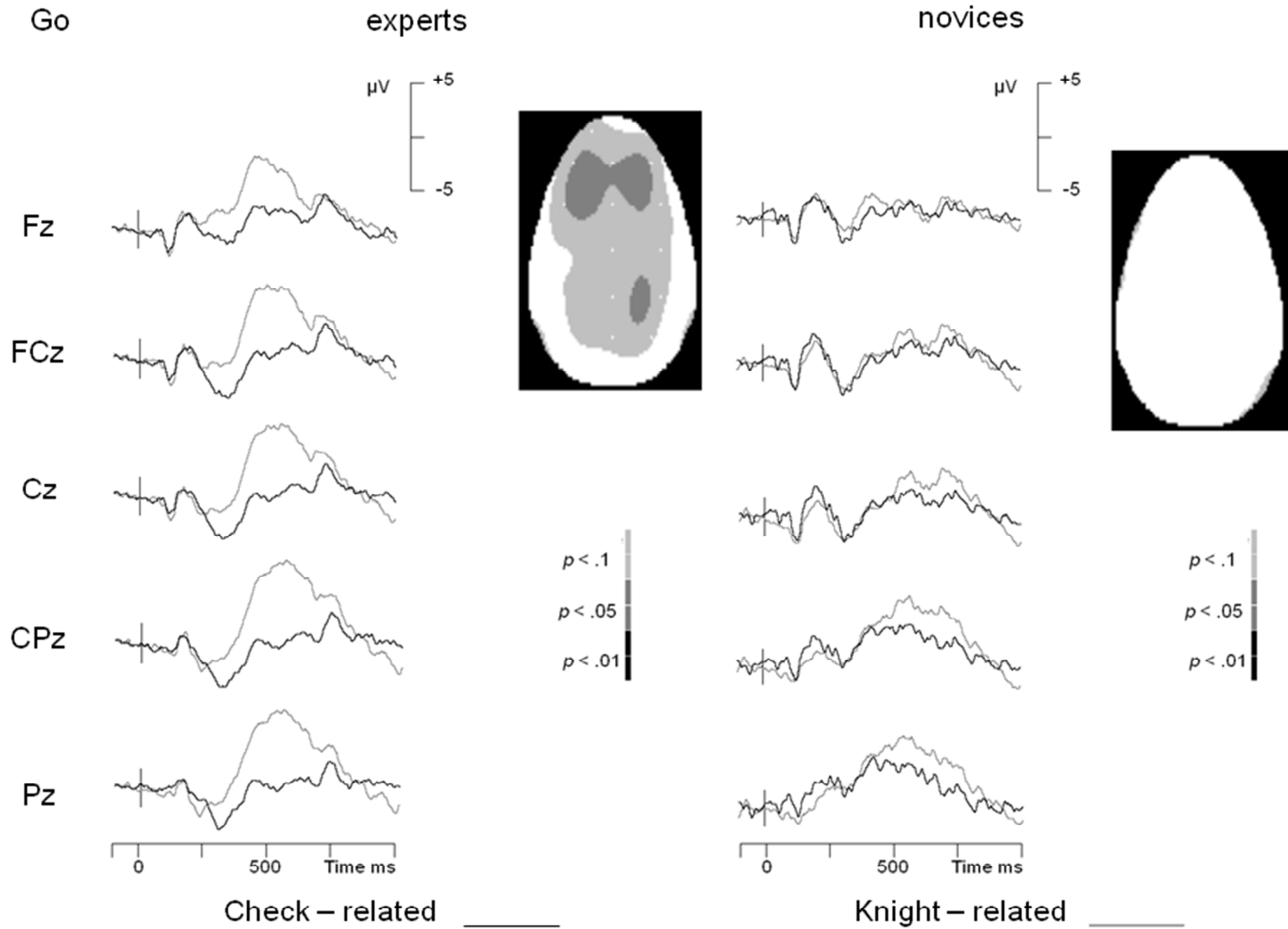
Pz

Check − related _____
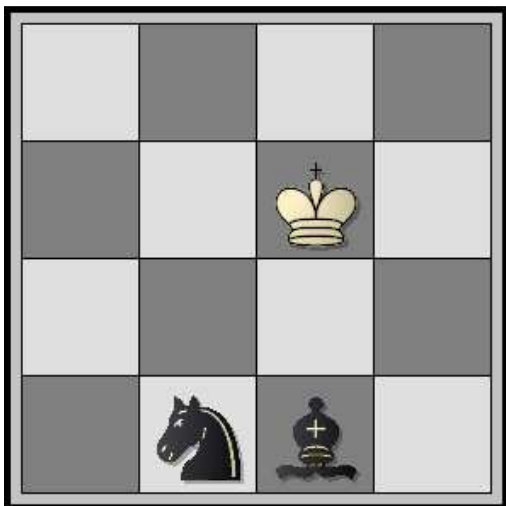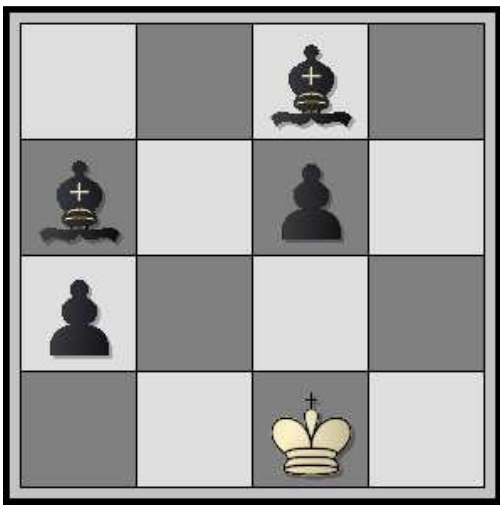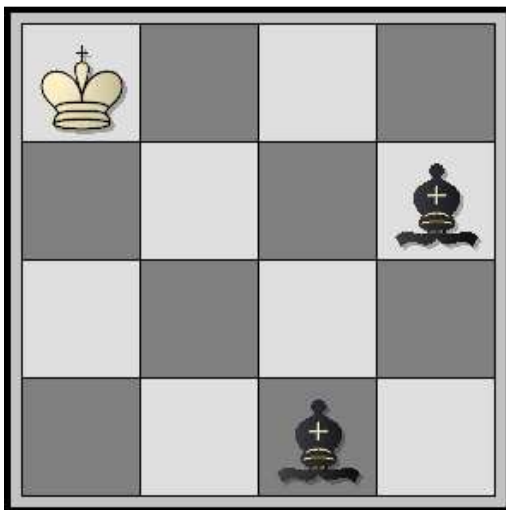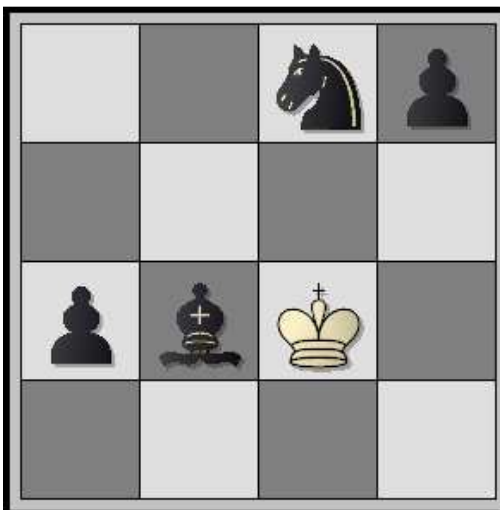
Knight − related _____
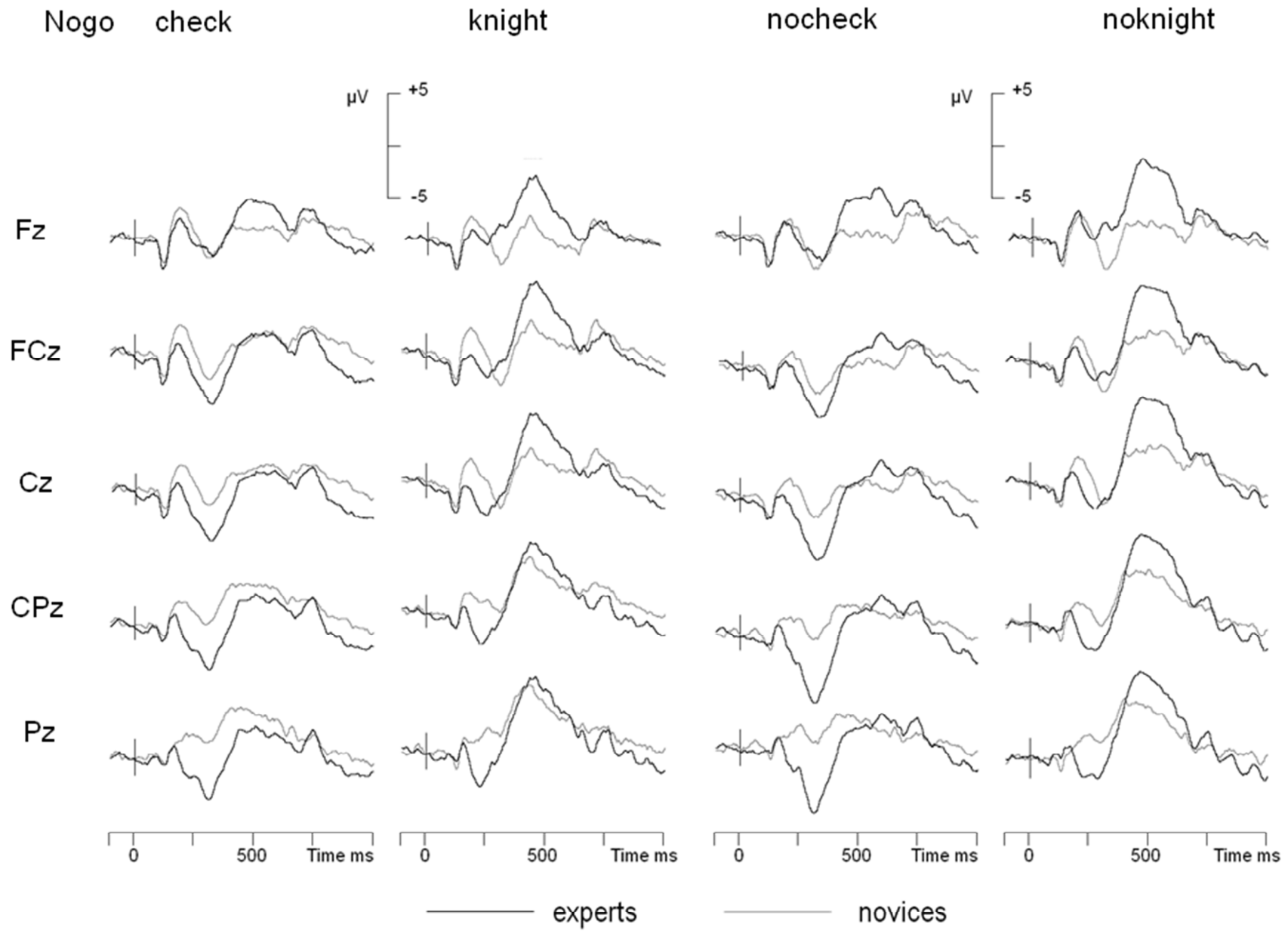
Figure legends.

Figure 1. All stimuli consisted of a 4 x 4 chessboard on which there was a white king plus a black knight and black bishop, e.g., (a), or a white king plus two black bishops, e.g., (b) or the same with the addition of two pawns, e.g., (c, d). With every combination of pieces, the white king either was in check (e.g., top row) or was not in check (e.g., bottom row). Each stimulus was presented for 0.5 s and there was a 4 s interval between trials, during which a grey screen was presented at mean luminance and with a central fixation cross. Behavioral responses were recorded from a single button that participants pressed with their (dominant) right hand.

Figure 2a. Grand average ERPs for Nogo trials for all experimental conditions at midline electrodes. The column headings refer to the target for "go". Experts: black trace, age-matched novices, grey trace. The stimulus onset was at 0 ms.

Figure 2b. Grand average ERPs for Go trials for all experimental conditions at midline electrodes. The column headings refer to the target for "go". Experts: black trace, age-matched novices, grey trace. The stimulus onset was at 0 ms.

Figure 3. Scalp topography of grand mean ERPs to chess stimuli for all experimental conditions, averaged across 275 - 325 ms interval (left) and 450 – 550 ms interval (right).

Figure 4a. Within-groups grand mean ERPs are shown for Nogo trials. Experts' data are shown on the left, novices' on the right. Black: check + nocheck, Grey: knight + noknight. The scalp maps are based on the grand mean ERP amplitudes averaged across the 350-450 ms interval, from which paired-samples *t*-values of the differences between check-related and knight-related conditions were calculated. The grey scale shows a conversion to levels of significance (*p* – values Bonferroni-corrected across electrodes).

Figure 4b. Within-groups grand mean ERPs are shown for Go trials. Experts' data are shown on the left, novices' on the right. Black: check + nocheck, Grey: knight + noknight. The scalp maps are based on the grand mean ERP amplitudes averaged

across the 350-450 ms interval, from which paired-samples *t*-values of the differences between check-related and knight-related conditions were calculated. The grey scale shows a conversion to levels of significance (*p* – values Bonferroni-corrected across electrodes).

Tables.

Table 1. Comparison of characteristics and chess experience of expert and novice groups

Table 2. The table illustrates the experimental design consisting of four blocks of stimuli (order counterbalanced) presented to all participants: and each block was subdivided into Nogo and Go trials. The main ERP results are based on the more numerous Nogo trials, with supplementary data from Go trials.

Table 3. Behavioral accuracy scores for experts and novices for the eight conditions shown in Table 2.

Table 3. ERP ANOVAs for Nogo and Go trials. The table shows all significant effects on the amplitude of P1, N2 and P3.