Journal of Expertise
2023. Vol. 6(1) © 2023.

ISSN 2573-2773

Templates But Not Emotions Facilitate the Information Flow Between Long-Term and Working Memory: A Sternberg Study with Chess Experts

Philippe Chassy[1], Rick Lahaye[2], and Fernand Gobet[3]
[1]Mathematical Psychology Laboratory, University of Liverpool, UK
[2]ChessZebra, Vlaardingen, The Netherlands
[3]Center for Philosophy of Natural and Social Science, London School of Economics and Political Science, UK

Correspondence: Philippe Chassy, Philippe.Chassy@liverpool.ac.uk

Abstract

Chess grandmaster Garry Kasparov played 30 games simultaneously in 2010; with about 25 seconds per move, he managed nevertheless to win all of them. How experts can perform at such a high level has always puzzled psychologists. Decades of research have documented that such performance results primarily from long-term memory, sophisticated memory structures termed templates. Templates organize huge-amounts of domain-specific material into functional units that ultimately enable instantaneous understanding through their processing in working memory. They also were theorized to make experts less sensitive to the influence of incidental emotions. The present paper examined whether the use of templates comes at a time cost and supresses the influence of incidental emotion. Thirty club players and 30 expert chess players undertook a short-term memory scanning task after being primed by either negative, neutral, or positive emotional images. Results indicate that experts are not only more accurate but are also faster than club players in scanning the content of their memory, even when it holds more information. This apparently counterintuitive result is accounted for by the notion that templates do not form in isolation but likely modify the structures that permit their retrieval in long-term memory. The emotion variable failed to reach statistical significance, which is interpreted in the light of the limited options to induce emotions in an experimental setting. The significance of our findings for theories of expertise is discussed in depth.

Keywords

Chess, skill, IAPS, incidental emotions, positive emotions, Sternberg's task, valence, visual cache, working memory

Introduction

Experts display high levels of accuracy in solving problems (Chi et al., 1982; Nokes et al., 2010), and they make correct decisions in complex situations, even under time or emotional pressure (Klein et al., 1986; Schläppi-Lienhard & Hossner, 2015). A striking example of the superiority of experts is found in the ability of chess professionals to play numerous games simultaneously (Gobet & Simon, 1996a). For example, Gary Kasparov played simultaneously against 30 players at Tel Aviv University in 2010. He would walk from one chessboard to the next and play his move; his average thinking time has been reported to be 25 seconds (Friedman, 2010). Kasparov won all games.

Some professionals have pushed the cognitive challenge even further by playing simultaneous games blindfolded (Fine, 1965; Hearst & Knott, 2009). In such cases, the player sits at a table while the moves are communicated orally. The player has to reconstruct all the positions[1] in the mind's eye and play from memory. This amazing cognitive ability has been demonstrated many times in the course of history. Only three years before becoming world champion, in 1927, Alexander Alekhine played 26 games simultaneously relying on his memory. In this exceptional performance, he scored 16 wins, 5 draws and only 5 losses.

Cognitive psychology has demonstrated that these skills are not disjointed competencies but stem from one another. Salient features of the position are quickly encoded in working memory through the activation of a template; relevant knowledge, in turn, guides attention towards locations of interest for finding further cues. Due to this recursive process of building an internal representation of a position, the representation held in working memory orients forward thinking and decision-making processes. All the cognitive processes underpinning chess performance are thus relying on memory recognition. It is because experts have a huge amount of domain-specific knowledge that they can solve problems fast and accurately. Knowledge is stored in specific structures, called chunks (Chase & Simon, 1973), which increase the amount of information held and processed in working memory at a given time (Norris & Kalm, 2021; Thalmann et al., 2019). As expertise develops, chunks are recursively integrated into large structures, termed templates (Gobet & Simon, 1996b), that organize domain-specific information, and so provide a sound understanding of the most complex situations. An example of template formation would be the ability to use typical sentences when one is learning a second language. Sentences are made of combination of basic elements (i.e., letters) that combine to form words, themselves being combined into phrases and then sentences. Moving from letters to words requires the learning of implicit rules of pronunciation of groups of letters. The learning of phrases and sentences requires one to understand the underlying logic in how words of different kinds combine to create and convey meaning. In a similar manner, templates in chess are combinations of basic patterns that form rich structures. Their rapid encoding into working memory ultimately enables players to make correct decisions rapidly (Chassy & Gobet, 2011). If much research has focused on the mechanisms whereby templates are formed in long-term memory, much less time has been devoted to examining how they are handled by working memory mechanisms. The present paper is aimed at remedying this gap.

The puzzle as to how experts make correct decisions in complex situations has been solved when it was realized that it is memory more than intelligence that underpins expert performance. Several lines of research converge to support the idea that templates encapsulate huge amounts of domain-specific knowledge (Gobet & Simon, 1996b). The grouping of information into one memory unit provided by templates allows players to represent a huge amount of material in working memory. Each template is made of an invariant structure that encapsulates the essence of the position and additional variable slots that can encode different patterns of pieces in specified locations. An example is the so-called isolated pawn; This is a pawn structure that defines strategic objectives and can arise from various chess openings (e.g., Queen's Gambit and Caro-Kann). The high number of pieces encoded by the template enables immediate memory encoding of the complex set of defensive and offensive interactions. The pawn structure is invariable in the center but the specific location of the pieces around the pawn structure call for different tactical maneuvers to serve the strategic purposes. Templates organize material in such a way that their activation in long-term memory spreads to a web of domain-specific information. For chess players, this mechanism translates as a retrieval of the essential strategic features of the position and the retrieval of potential tactical maneuvers that could help solve the problem at hand. The value of templates is thus not only that they encapsulate information but also that they connect to knowledge that is relevant to the type of situation that is being faced. Templates have been shown to operate quickly (Gobet & Simon, 2000): While club players needed about 5 seconds to recall a chess board with about 40% accuracy, professionals could achieve an accuracy rate as high as 90% within two seconds. Templates thus provide experts with a perceptual and memory advantage within the first seconds. Because templates are long-term memory structures, they allow manipulating complex representations in the mind's eye by avoiding cognitive load. Templates constitute the basis of expert memory skills and so the basis of expert performance in blindfold chess (Campitelli & Gobet, 2005).

The formation of templates in long-term memory is a lengthy process. These develop upon the previous acquisition of rigid bits of information called chunks (Chase & Simon, 1973). It has been estimated that to reach expert level, players need to have a database of about 300,000 chunks stored in their long-term memory (Gobet & Simon, 2000). It is because so much information needs to be organized and integrated into sophisticated structures that expertise acquisition is such a time-consuming process. Studies have indicated that the amount of time necessary to become a chess professional is on average about 10,000 hours (Gobet & Campitelli, 2007). This result is not specific to chess and has also been found in other domains such as music (Ericsson et al., 1993) or professional football (Williams & Hodges, 2005). A consequence of the accumulation and constant reorganization of knowledge is the re-structuration of the biological networks processing domain-specific information: Experts display structural differences in the brain regions that process domain-specific information. Early evidence of experience-dependent biological modifications was collected with taxi drivers, who were shown to have larger amounts of gray matter in posterior hippocampi (Maguire et al., 2000), the brain regions in charge of spatial navigation, than controls in the study. Studies with expert musicians have also indicated that experts are relying on restructured brain areas to perform at a high level (Gaser & Schlaug, 2003). This plasticity-dependent reorganization of the expert brain extends to cognitive domains such as mathematics (Popescu et al., 2019).

As expected, expert chess players display the same features. It has been largely documented that their performance comes from their superior knowledge, stored in visual long-term memory (Bilalić et al., 2011; Guida et al., 2012). As indicated above, templates organize the problem situation to provide the perceiver with an immediate mental representation of it. In addition, they provide access to a wealth of domain-specific information, including a set of potential solutions. These memory structures, sometimes involving large-scale networks, are complex and so are demanding for the cognitive system. Their retrieval and manipulation in working memory could be interpreted as generating a time cost. The maximum number of items that an expert can hold in visual working memory has been the subject of intense debate (Gobet & Clarkson, 2004; Luck & Vogel, 2013), with the conclusion that four items would be the typical limit (Cowan, 2010). It is worth outlining that the visual working memory span differs from the verbal memory span, the latter being initially thought be around seven items (Miller, 1956). With a maximum span of four visual items, individuals would start experiencing difficulties in manipulating four items and would drastically lose in accuracy above that threshold. Research on chess has suggested that one template can encode large portions of the chessboard, including an entire position. On these premises the average maximum working memory span would be four positions held at a time (Gobet & Clarkson, 2004; Gobet & Simon, 1996b). Considering that each template encodes up to 12 pieces, if not more, implies that working memory can potentially store and manipulate the nature and location of about 48 pieces—a huge amount of information. Hence, when a beginner will spend cognitive resources and time in constructing the representation of a situation by combining small chunks, an expert will rapidly and efficiently retrieve and update a template from memory. The apparently paradoxical conclusion from this reasoning is that experts will not only be more accurate but also faster than beginners as they will require less information transfer between long-term and working memory.

One of the main factors that can interfere with working memory processing, and thus disturb the normal flow of information processing, is emotions (Kensinger & Corkin, 2003; Osaka et al., 2013). Like laypeople, experts can have their judgements and decisions altered by emotions. Working memory preferentially processes items that are emotionally loaded (Harris & Pashler, 2005). If emotions related to the task are expected to affect performance for they attract attention to potential risks, emotions unrelated to the task are expected to be ignored. Yet, incidental emotions have been shown to affect working memory as well (Yang et al., 2013). This influence of emotions sometimes leads people to misjudge situations and make wrong decisions (Blanchette & Richards, 2010). These interfering emotions might hamper performance (Vargas et al., 2019). These effects reflect that emotions, such as stress, have a huge negative influence on working memory (Duncko et al., 2009). Chess is a field of expertise where decisions made under emotional duress can be fatal to the decider. In spite of the time allotted to make moves, chess games occasionally finish with the competitors having to make many decisions with only a few seconds per move. As documented by several studies, chess decisions made under time pressure are not optimal but are still largely sufficient to solve the problem with experts retaining their advantage over non-experts (Blanch et al., 2020; Burns, 2004; Calderwood et al., 1988). Chess players have developed some form of immunity to incidental emotions to focus on the task and as such they constitute a good population to study the isolation of incidental emotions.

Working-memory processing has been largely investigated with a broad spectrum of experimental paradigms. The memory scanning task (Sternberg, 1966) has proven particularly useful in unravelling the mechanisms that underpin working memory and in particular the speed at which working memory operates. We used the Sternberg paradigm to test the following predictions. First, in line with template theory, experts will be faster in encoding information into memory and thus should be faster in completing the task. Second, as templates are stable long-term memory structures, they will allow a more accurate representation of the position than a collection of chunks would, and thus experts will be more accurate than non-experts in completing the task. Incidental emotions should affect more a working-memory representation that is built from a collection of chunks than a representation that is built from a unique template. As a consequence, we would expect experts to be less affected in term of reaction time and accuracy than non-experts.

Method

Participants

Sixty players (5 females) participated on a voluntary basis and were paid 10 euros. They were recruited through advertisement in several chess clubs and tournaments. Participants' mean rating was *M* = 1995.67 Elo (*SD* = 238.25 Elo), with a mean age of *M* = 37.72 years old (*SD* = 14.59). Based upon the cut-off rating of 2000 Elo established by Elo (1978), players were allocated to either the club level group (rating < 2000 Elo) or the expert group (rating ≥ 2000 Elo). Thirty players with a mean Elo rating of 1795.10 Elo (*SD* = 118.21 Elo) constituted the club group and thirty players with a mean Elo rating of 2196.23 Elo (*SD* = 135.12 Elo) constituted the expert group. The Elo rating between the two groups was significantly different, *t*(58) = 12.23, *p* < .001. Importantly, the age between club (*M* = 38.00, *SD* = 15.97) and expert players (*M* = 33.43 *SD* = 12.93) did not differ statistically, *t*(58) = 1.22, *p* = .23. Ten players of each group were assigned to one of the three emotional conditions (negative, neutral, or positive). One expert player in the positive emotional condition completed 56 out of the 60 trials and did not complete the subjective ratings of mood. The data from this participant were kept as 93% of the experiment was completed and, importantly, the participant did respond to at least one trial in all conditions. Ethical approval was obtained for the Department of Psychology at Brunel University, and participants signed a consent form.

Task and Design

The short-term memory scanning task, first introduced by Sternberg (1966), was used to test whether working memory load, expertise, and emotional priming influence working memory processing of chess material in club and expert chess players. We adapted the paradigm to implement emotional priming. The typical sequence of trials is illustrated in Figure 1. Working memory load was implemented as the number of positions presented in a sequence with either 3, 4, or 5 items. Each position was displayed for 5 seconds, followed by a 200 ms mask. The length of the sequence was randomized across trials. After the sequence of positions, the emotional inducer was presented for 2 seconds, followed by the mask. Finally, a probe position was presented until the participants responded whether it was part or not of the sequence of items displayed. In half the trials, the probe was not part of the list. Due to a programming slip, in the 4-item condition the probe was absent in 11 trials and present in 9 trials rather than in 10 trials. Accuracy and response time were recorded for each trial. Participants were instructed as follows: “You are asked to identify whether a probe position is part of the list of positions. Press P if you think the probe was present and A if you think the probe was absent from the list. Please reply as quickly as possible while being confident in your answer.”

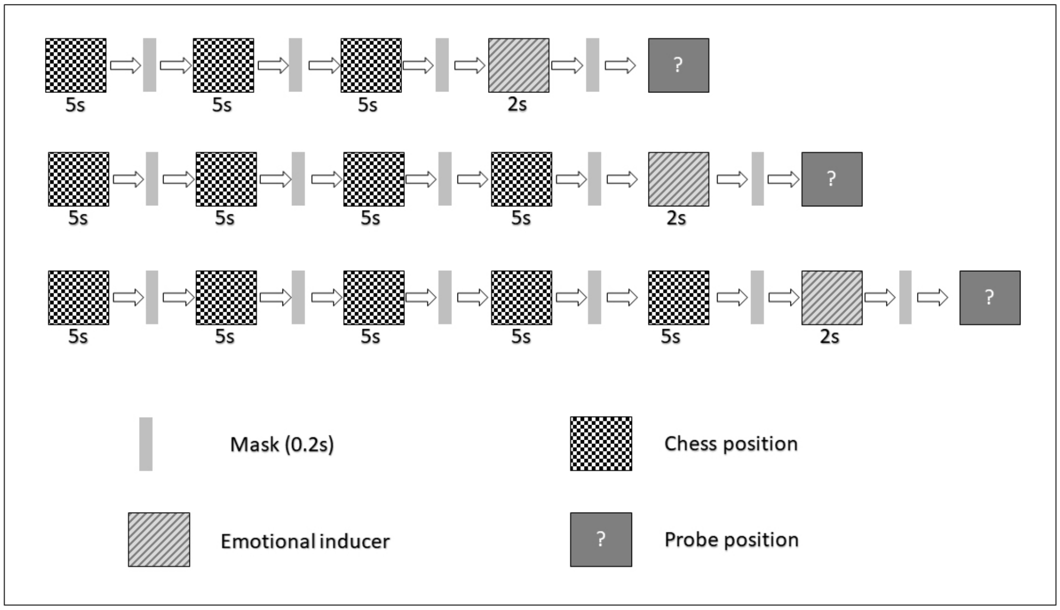

Figure 1. Trial structure of the Sternberg task.

To control for potential confounds linked to manipulating emotional responses, the participants were asked to (a) rate their mood before and after the experiment, (b) evaluate whether they believed emotions impacted their reaction time and their accuracy, (c) rate how difficult they found the experiment to be, and (d) rate on 9-point Likert scales the emotional inducers with respect to valence and arousal. The last three activities occurred at the end of the experiment.

Our design thus implemented four independent variables. Two variables were between subjects: skill (club players vs. experts) and emotional priming (negative, neutral, or positive). Two variables were within subject: working memory load (3, 4, or 5 items) and probe (present vs. absent).

Material

The material for the Sternberg task consists of chess positions for filling memory and emotional inducers. The latter were presented before the probe. Sixty negative, 60 neutral and 60 positive images were selected from the International Affective Picture System (IAPS; Lang et al., 2001), a standardized database of images widely used to induce emotions experimentally. Numerous experiments have used IAPS as emotional inducers (e.g., Barke et al., 2012; Drače et al., 2013; Gerger et al., 2014; Yun et al., 2019). Three sets of 60 images were selected to implement the three levels of the emotion variable: neutral, negative, and positive (see Appendix 1 for details). The images were selected based upon the average ratings collected in previous studies.

Two hundred and forty chess positions were selected from a commercial database. Only games from professional players were selected (ratings > 2500 Elo). Professional games were selected as they maintain the highest level of internal consistency and thus avoid displaying features that would make them unique, facilitating their recognition. In addition, a list of 60 probe positions was created by selecting 30 positions from the list of stimuli and 30 additional positions from the commercial database, using the same stringent selection criteria (the details of the positions are provided in Appendix 2 available here: https://osf.io/uvtx7/).

The questions for subjective feelings and evaluation were all implemented as a computer program. Participants were asked to rate their mood on a nine-point Likert scale ranging from very negative (1) to very positive (9), and to rate their arousal on a nine-point Likert scale ranging from negligible (1) to very high (9). They were also asked to rate the difficulty of the task on a five-point Likert scale ranging from 1 (easy) to 5 (difficult). Participants were asked whether they believed that emotions influenced their reaction times and whether emotions influenced their accuracy. Both questions were phrased to receive a closed answer (yes or no). Each of the emotional inducers were rated on nine-point Likert scales. The first question required the participants to rate the valence of the emotional inducers ranging from 1 (extremely negative) to 9 (extremely positive). The second question required participants to rate the arousal generated by the inducer on a scale ranging from 1 (low) to 9 (very high).

An electronic version of the Likert scales was designed to assess the mood of the participant before and after the experiment.

Procedure

After giving informed consent, the participants sat in front a computer where they started by providing their demographic information (age and gender) and Elo rating. They then proceeded by filling the two-question mood questionnaire. The participants underwent practice trials to get used to the speed and format output of the experiment. At this stage, participants undertook the 60 trials of the experiment. The working memory load of each trial was randomized as well as whether the probe was present in the list of items. At each trial, reaction time, response, and correctness were recorded. Once the participants completed all the trials, they filled in the two-question form on mood and then provided their subjective answers. Finally, the participants rated all the emotional inducers one after another, in a random order, on valence and arousal. In total, participants processed 240 positions in 60 trials.

Recorded Variables and Preprocessing

As an indicator of performance, we calculated the number of correct trials over the total number of trials. The resulting variable, *hit ratio*, was used to test the hypotheses on performance. Response times were submitted to 3 filters. The first filter consisted in excluding the error trials, which led to 399 trials (11%) being discarded from future analyses on RTs. The second filter consisted in discarding all trials inferior to 200 ms. As the shortest response time was 0.702 s there were no trials discarded as a result of applying this second filter. The third filter was applied to discard response times superior to the mean plus three times the standard deviation. This filter led to the deletion of a further 42 trials (1%). Technically, 75 trials were meeting the criteria for the third filter but 33 of these also included an error answer and thus were already excluded from the application of the first filter. After applying the three filters, the RT data consisted of 88% of the total sample. RTs were not normally distributed and were thus log-transformed.

Results

The 60 players performed with a mean hit ratio of *M* = .89 (*SD* = .15) across conditions. The mean response time to correct trials across the 60 participants and six conditions was *M* = 3.32 s (*SD* = 1.21 s). To evaluate the influence of experimental fatigue, linear-regression analyses were performed by regressing average log-transformed reaction times and hit ratios on trial number (T). The analyses revealed a significant linear trend for the log-transformed RTs, but not for hit ratios.

$$\text{hit ratio} = -0.118 \times \text{T} + .572, p = .24$$

$$\log(\text{RT}) = -0.000836 \times \text{T} + 0.492971, p < .001, r^2 = .329$$

We first report the data on the subjective evaluations of the participants. Then, we analyze response time and hit ratios, respectively.

Subjective Ratings of the Emotional Inducers

Predictably, the subjective mean evaluation of valence by the players varied across the three conditions of emotion, *F*(2,3597) = 961.008, *p* <.001, *MSE* = 2.397 with positive images (*M* = 5.85; *SD* = 1.405), being evaluated as being more positive than neutral images (*M* = 5.05; *SD* =1.557), themselves evaluated as being more positive than negative images (*M* = 3.16; *SD* = 1.67). Players also evaluated that positive (*M* = 4.47; *SD* = 1.985) and negative (*M* = 4.10; *SD* = 2.567) images induced higher levels of arousal than neutral images (*M* = 3.70, *SD* = 2.155), *F*(2,3597) = 35.190, *p* < .001, *MSE* = 5.057. These results confirm the efficacy of the IAPS standardised image set in generating moderate emotions in experimental designs.

Subjective Ratings of Mood

Players rated their mood on the 9-point scale before the experiment with an average valence of 6.58 (*SD* = 1.22) and an average arousal of 4.34 (*SD* = 1.82). Table 1 reports the average valence and arousal ratings by between-subject conditions.

Table 1. Subjective ratings of mood state before and after the experiment for each group of participants (Skill x Emotion).

		Valence		Arousal	
Skill	Emotion	Before	After	Before	After
Club	Negative	6.60 (1.35)	6.40 (1.90)	3.40 (2.01)	4.10 (2.18)
	Neutral	7.30 (1.06)	6.10 (1.85)	4.60 (2.17)	4.00 (2.16)
	Positive	7.20 (1.03)	6.50 (0.97)	4.50 (1.90)	4.30 (1.83)
Expert	Negative	6.20 (1.40)	5.30 (1.34)	4.70 (1.77)	4.10 (1.73)
	Neutral	6.10 (0.88)	6.20 (1.23)	4.40 (1.35)	4.80 (1.13)
	Positive	6.00 (1.12)	6.11 (0.78)	4.44 (1.74)	4.44 (1.42)

Note. Data are Mean (Standard deviation).

Two Skill (club vs. expert) × Priming (negative, neutral, and positive) × Test (pre vs. post) analyses of variance (ANOVAs) were conducted separately on subjective ratings of valence and arousal to examine the influence of emotional priming subjective ratings for arousal and valence.

The ANOVA on valence revealed that the factor Test had a significant impact, *F*(1,53) = 9.12, *p* < .01, *MSE* = 0.70, with the subjective ratings being overall lower after the experiment (*M* = 6.10; *SD* = 0.42), as compared to before the experiment (*M* = 6.57; *SD* = 0.57). The other main factor with a reliable impact was Skill, *F*(1, 53) = 5.53, *p* = .02, *MSE* = 2.64, with experts feeling less positive (*M* = 5.99; *SD* = 0.31) than club players (*M* = 6.68; *SD* = 0.47).

The last main factor, priming, did not yield a significant result, *F*(2, 53) = 0.63, *p* = .94, *MSE* = 2.64. The two-way interactions were not significant: Test × Skill, *F*(1, 53) = 2.33, *p* = .13, *MSE* = 0.70; Test × Priming *F*(2, 53) = 0.30, *p* = .74, *MSE* = 0.70; and Skill × Priming *F*(2,53) = .06, *p* = .94, *MSE* = 2.64. The triple interaction Test × Skill × Priming was significant, *F*(2, 53) = 3.88, *p* = .03, *MSE* = 0.70, indicating that the influence of emotional priming affects how players of different skill have been responsive to their change in mood following the testing.

The results of the ANOVA on arousal did not yield any significant effect : none of the main effects, Test, *F*(1, 53) = 0.60, *p* = .81, *MSE* = 1.23, Skill, *F*(1, 53) = 0.60, *p* = .44, *MSE* = 5.36, and Priming, *F*(2, 53) = 0.32, *p* = .72, *MSE* = 5.36, were significant, nor were any of the interactions: Test × Skill, *F*(1, 53) < .01 , *p* = .93, *MSE* = 1.2; Test × Priming *F*(2, 53) = 0.06, *p* = .94, *MSE* = 1.23; Skill × Priming *F*(2,53) = .17, *p* = .85, *MSE* = 5.36; and Test × Skill × Priming, *F*(2,53) = 2.76, *p* = .07, *MSE* = 1.23.

Response Times

Table 2 reports the descriptive statistics for each experimental condition. Log-transformed response times were submitted to an ANOVA with two within-subject and two between-subject variables. Memory load (3, 4, and 5 items) and probe (absent vs. present) were entered as within-subject variable. Emotion (negative, neutral, and positive) and skill (Club vs. Expert) were entered as between-subject variables.

Table 2.. Descriptive statistics of reaction times (s) in each experimental condition

		Working memory load					
		3 items		4 items		5 items	
		Probe		Probe		Probe	
Emotion	Skill	absent	present	absent	present	absent	present
Negative	Club	3.85 (1.44)	3.28 (0.84)	4.38 (1.41)	3.70 (1.31)	4.19 (1.47)	3.67 (1.51)
	Expert	3.40 (1.23)	3.22 (1.51)	3.09 (1.01)	2.94 (1.06)	3.44 (1.19)	3.10 (0.94)
Neutral	Club	3.38 (1.06)	3.22 (0.93)	3.62 (1.17)	3.47 (1.06)	3.46 (0.99)	3.34 (0.71)
	Expert	2.76 (0.94)	2.56 (0.68)	2.95 (0.87)	3.04 (0.86)	3.17 (1.17)	2.86 (0.85)
Positive	Club	3.62 (1.51)	3.54 (2.43)	4.01 (2.00)	3.15 (1.51)	3.71 (1.42)	3.65 (1.58)
	Expert	2.98 (1.06)	2.80 (0.54)	2.80 (0.53)	2.99 (0.61)	3.08 (0.68)	3.11 (0.61)

Note. Mean (standard deviation)

Table 3 reports the relevant statistics for each source of variance. The main effects of memory load, skill, and probe significantly affected response times. Experts performed the task faster (*M* = 3.02 s, *SD* = 1.72 s) than club players (*M* = 3.62 s; *SD* = 1.38 s) – a. difference of 600 ms. The presence of the probe (*M* = 3.20 s, *SD* = 1.16 s) was spotted faster than its absence (*M* = 3.44 s, *SD* = 1.24 s), with an average difference of 240 ms. Figure 2 illustrates the mean response time for each working memory load condition; the differences are reliable, *F*(1, 54) = 12.70, *p* < .001. Among all the interactions, only the triple interaction between working memory load, skill, and priming was significant.

Table 3. Results of the skill (2) × working memory load (3) × probe (2) × priming (3) ANOVA on reaction times

Source	Degrees of freedom		*F*	*p*	*MSE*
	Between	Within			
Skill	1	54	5.522	0.022*	0.081
Working memory load	1	† 54	8.765	0.000*	0.003
Probe	1	54	4.265	0.044*	0.009
Priming	2	54	0.616	0.544	0.081
Working memory load × probe	2	108	0.018	0.982	0.004
probe × skill	1	54	2.759	0.103	0.009
Working memory load × skill	2	108	0.414	0.662	0.003
Working memory load × priming	4	108	1.181	0.323	0.003
Probe × priming	2	54	1.067	0.351	0.009
Skill × priming	2	54	0.035	0.966	0.081
Working memory load × probe × priming	4	108	0.827	0.511	0.004
Working memory load × probe × skill	2	108	1.623	0.202	0.004
Probe × skill × priming	2	54	0.913	0.407	0.009
Working memory load × skill × priming	4	108	2.515	0.046	0.003
Working memory load × probe × skill × priming	4	108	0.30	0.88	0.00

Note. * Significant at α= .05, † Degrees of freedom have been corrected to lower bound to address non-sphericity, as revealed by Mauchly's *W(2)* = .86, χ^2 = 8.07, *p* = .02

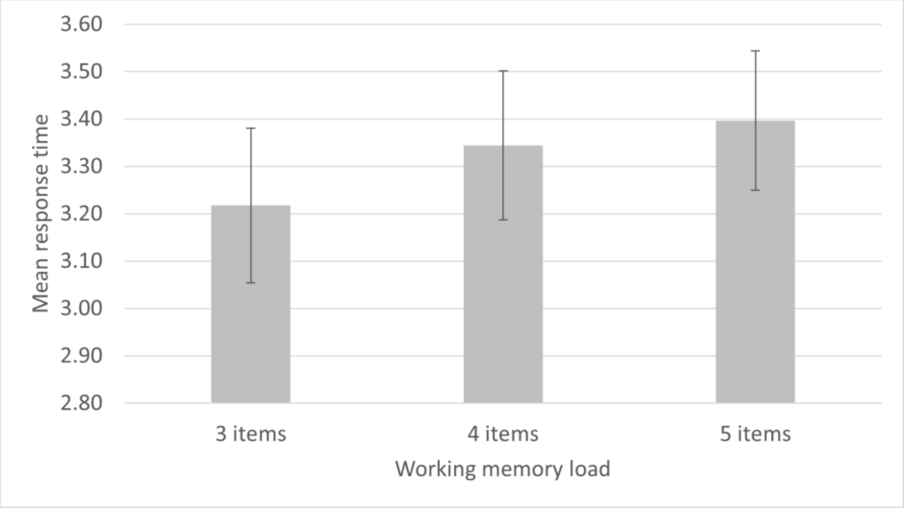

Figure 2. Average response time for each working memory load level. Error bars are standard errors.

Hit Ratio

Table 4 reports the descriptive statistics of hit ratio for each experimental condition. Memory load (3, 4, and 5 items) and probe (absent vs. present) were entered as within-subject variable. Priming (negative, neutral, and positive) and skill (Club vs. Expert) were entered as between-subject variables.

Hit ratios were submitted to an ANOVA with two within-subject and two between-subject variables. Memory load (3, 4, and 5 items) and probe (absent vs. present) were entered as within-subject variables. Emotion (negative, neutral, and positive) and skill (Club vs. Expert) were entered as between-subject variables. Table 5 reports the relevant statistics for each source of variance.

Table 4. Descriptive statistics of hit ratios for each experimental condition

		Working memory load					
		3 items		4 items		5 items	
		Probe		Probe		Probe	
Emotion	Skill	absent	present	absent	present	absent	present
Negative	Club	0.79 (0.20)	0.96 (0.10)	0.79 (0.15)	0.97 (0.05)	0.78 (0.11)	0.96 (0.05)
	Expert	0.92 (0.10)	0.99 (0.03)	0.80 (0.16)	0.99 (0.03)	0.82 (0.14)	0.97 (0.05)
Neutral	Club	0.74 (0.13)	0.94 (0.07)	0.72 (0.16)	1.00 (0.00)	0.65 (0.15)	0.98 (0.04)
	Expert	0.97 (0.07)	0.98 (0.04)	0.96 (0.05)	0.97 (0.05)	0.89 (0.15)	1.00 (0.00)
Positive	Club	0.71 (0.23)	0.99 (0.03)	0.69 (0.16)	0.97 (0.07)	0.68 (0.16)	0.96 (0.05)
	Expert	0.93 (0.09)	0.99 (0.03)	0.91 (0.09)	0.98 (0.05)	0.77 (0.14)	1.00 (0.00)

Note. Mean (standard deviation)

Table 5. Results of the skill (2) x working memory load (3) × target (2) × priming (3) ANOVA on hit ratios

Source	Degrees of freedom				
	Between	Within	F	p	MSE
Skill	1	54	33.520	0.000*	0.020
Working memory load	2	108	5.143	0.007*	0.009
Probe	1	54	156.345	0.000*	0.017
Priming	2	54	0.567	0.571	0.020
Working memory load × probe	2	108	7.089	0.001*	0.007
Probe × skill	1	54	27.282	0.000*	0.017
Working memory load × skill	2	108	1.283	0.282	0.009
Working memory load × Priming	4	108	0.582	0.676	0.009
Probe × priming	2	54	1.153	0.323	0.017
Skill × priming	2	54	2.683	0.077	0.020
Working memory load × probe × priming	4	108	1.226	0.304	0.007
Working memory load × probe × skill	2	108	1.460	0.237	0.007
Probe × skill × priming	2	54	4.150	0.021*	0.017
Working memory load × skill × priming	4	108	0.675	0.611	0.009
Working memory load × probe × skill × priming	4	108	1.744	0.146	0.007

Note. * Significant at $\alpha = .05$. All factors met Mauchly's sphericity assumption, no corrections were applied.

As indicated in Table 5, skill affected performance with experts (*M* = .94, *SD* = .16) performing better than club players (*M* = .85, *SD* = .17). The factor probe also affected results with trials in which the probe was present leading to more successful identifications (*M* = .98, *SD* = .05) than trial in which the probe was absent (*M* = .81, *SD* = .17). Performance was negatively affected with working-memory load increase, as shown in Figure 3.

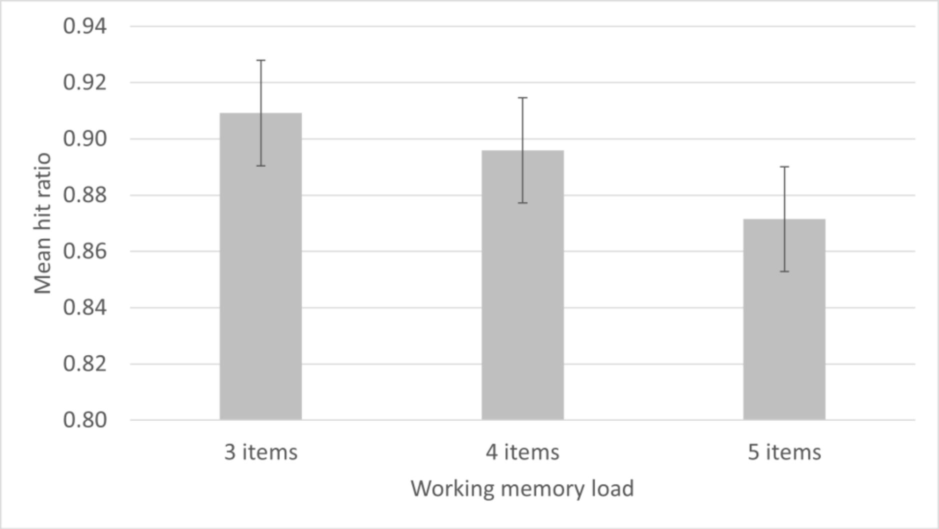

Figure 3. Performance as measured by hit ratios as a function of working memory load. Error bars are standard errors.

The interaction between probe and working memory load, pictured in Figure 4, reflects the increasing number of false positives that players experienced in scanning their memory as memory load increased. As shown in Figure 4, performance when the probe was in the list was not affected by working memory load.

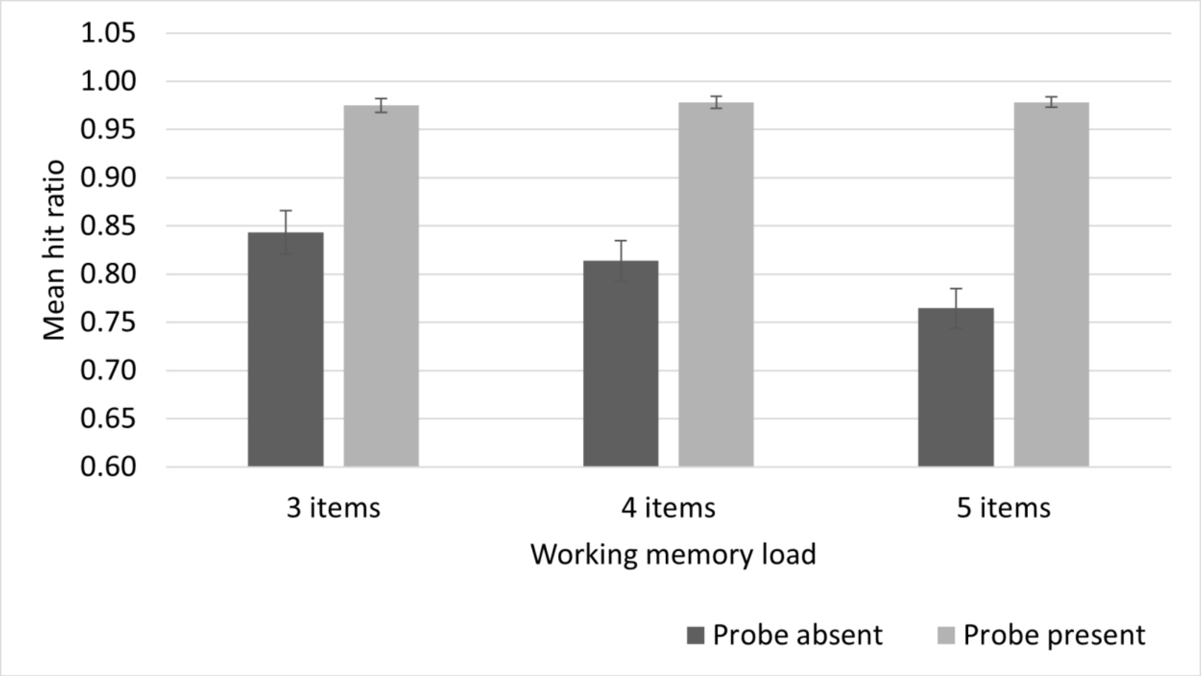

Figure 4. Mean hit ratios for the working memory load × probe interaction. Error bars are standard errors.

As Figure 5 indicates, the other two-way interaction that was significant was the skill × probe, which shows that club players were more affected by the absence of the probe than expert players. While experts experienced a moderate loss of percentage in performance in the no-probe condition as compared to the probe condition, club players experienced a drastic percentage drop. Finally, the triple interaction probe × skill × priming was also significant. Regarding the questions that the participants had to answer after the experiment, 50% of the club players and 51% of the experts stated that they believed that emotional priming affected their reaction times. As expected, experts rated the experiment ($M = 2.69$, $SD = 1.07$) to be easier than club players ($M = 3.50$, $SD = 1.17$), $t(57) = 2.78$, $p < .01$.

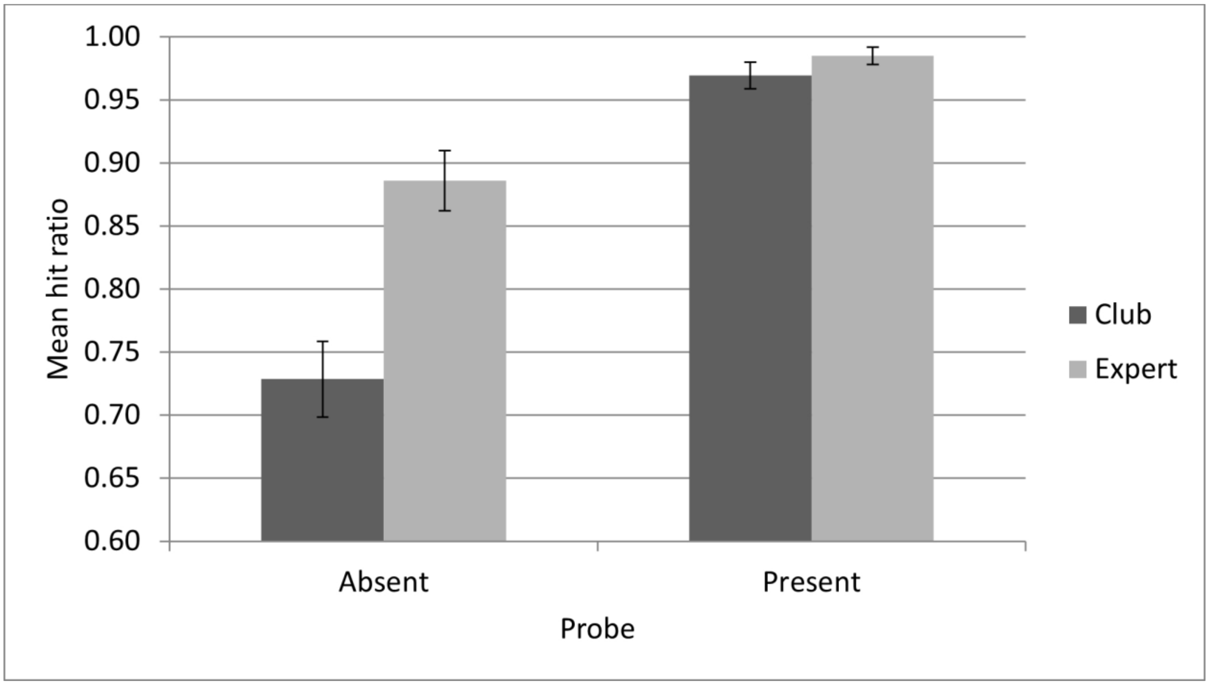

Figure 5. Mean hit ratios for the skill × probe interaction. Error bars are standard errors.

Discussion

In this experiment, the Sternberg scanning task was used to test the influence of emotions and working memory load on chess players' cognitive performance. We presented sequences of chess positions, varying from 3 to 5, to club and expert players. Players were emotionally primed with either a neutral, positive, or negative image before the presentation of the probe. We found a huge effect of skill on both reaction time and accuracy, with most of the errors being committed due to false-positive identifications. Emotions did not affect the behavioral results and the subjective ratings, in spite of the correct recognition by the players of the emotional valence of the images. The results are globally supportive of our hypothesis related to template theory and less so about the connection between emotion and cognition in chess players.

The hypotheses related to the effect of expertise on the accuracy and speed of working memory found support in our study. By achieving 94% of accuracy, experts display a superiority in scanning items that belong to their field of expertise. It is worth keeping in mind that positions in our experiment have an average of 18 pieces and thus memorizing 5 positions requires working memory to encode the location of 90 pieces on average. Expert memory is thus highly efficient within a few seconds of exposure of material. This result is consistent with experts' superiority in a number of other memory tasks and in line with template theory. Intriguingly, it also reveals the limit of memory as there are still 6% of positions that experts did not classify properly. The significant effect of probe indicates that errors were mostly false negatives. A potential explanation for this finding is that an exposure time of 5 seconds might not allow working memory a sufficient amount of time to build a complete representation of each position; as a consequence, probe positions that would share part of their material with one of the positions displayed in the trial could be misidentified as being the same. The significant 9% increase in performance that experts demonstrate as compared to club players might seem a minor achievement at first, but this is neglecting the fact that the group of lower skill in our study are club players with experience in competition. The significantly higher number of errors committed by club players was predicted by the theory but our results, thanks to the significant interactions involving probe, have uncovered the fact that most of club players are much more likely to commit false-positive identifications. As the club players recruited were intermediate players, we would argue that their chunks have not been combined yet to form new templates. The representation held in working memory is built from a combination of chunks rather than from a unique integrated memory template. Chunks allowed club players to perform well-above chance level; however, encoding of piece location into working memory was not sufficiently precise, leading to confusion. Yet, in spite of this cognitive limit, club players performed at 85%. In this context, that experts are able to improve even further by 9% to reach an overall mean accuracy of 94% truly is a testimony of the advantage that templates provide to players when encoding and manipulating information.

The other result highly supportive of template theory is the difference in reaction time. The mean difference of 600 ms means that experts were 17% faster than club players and supports the view that templates facilitate working memory processing. The question this finding raises is whether the time is gained at encoding the items into memory or at scanning the items once the probe is encoded. Two considerations lead us to suggest that experts save time at the encoding phase rather than at the scanning phase. First, eye tracking experiments (Blignaut et al., 2008; De Groot et al., 1996; Penttinen et al., 2013) show that experts encode more information per eye fixation than non-experts. Experts thus encode more information within the five seconds that were allowed for observing the probe. A second consideration is that the amount of time saved, 600 ms, is clearly larger than the time it takes to scan one more item. For example, the transition from 3 items to 4 items increased the mean reaction time by 127 ms and the transition between 4 and 5 items costed the players an additional 52 ms. These figures are well below the scale of the 600 ms gain that experts display over club players and thus it is not possible that experts gain so much time on a process that is so fast. The increase in quality of processing and simultaneous reduction in speed constitute evidence in support of the hypothesis that templates engage the reorganization of the brain (Guida et al., 2012) through the development of structures that connect long-term knowledge to working memory. As the formation of neuronal connections is dependent upon activity-dependent neural plasticity (Kandel, 2001), our results contribute to establish a link between biological processes and improvement of human performance in processing domain-specific stimuli.

The significant effect that the probe had on performance allows understanding further how templates improve working memory performance. First, we note a potential ceiling effect when the probe was present. Both club and expert players displayed a very high rate of correct hits with an astonishing 98% of correct trials. In contrast, the average performance was significantly lower when the probe was absent, with the players correctly recognizing that the probe was absent in 81% of the trials. It must be noticed that a performance of 81% is still well above chance performance and shows that templates encode chess positions with a high level of accuracy in working memory in spite of the large amount of information that is to be processed. Yet the question of which mechanism can lead to a 17% drop in performance should be posed. We would suggest interpreting this difference in performance as resulting from two factors. The first factor that might fuel the rate of false recognition is that players had to process a large number of positions within the relatively short time frame of the experiment. Their templates were thus submitted to an intense series of activation in the exposing phase and deactivation once the trial was finished; this for each trial for 60 trials. Resilient activation from previously used templates or of the same templates with a different instantiation of the slots might have led to confusion. The second factor is linked to how templates encode information. Only when templates are well-developed and stable memory structures do they encode the core and the flexible slots with high accuracy, but template formation takes a significant amount of time as it requires the reorganization of brain circuits (Guida et al., 2012). Their formation includes phases where the slots that could be instantiated are not fully formed and information is coded with some uncertainty (Gobet, Lane, Croker, Cheng, Jones, Oliver, & Pine, 2001). In club players, templates are not fully formed and thus many positions might be confused. This second factor contributes not only to the general rate of false recognition but also accounts for the effects of skill and probe. It is worth noting that, taken together, these results strengthen the template hypothesis of chess expertise.

The findings of the present experiment are in line with previous studies using the Sternberg paradigm. Memory load affected both response time and hit ratio. Regarding the increase in response time with memory load, the results are consistent with other experiments using the Sternberg task: The more loaded the memory was, the more time participants required to scan their visual short-term memory. Taking into account the fact that visual memory span is around 4 items (Cowan, 2001), we suggest that participants had difficulties matching the probe when the content of short-term memory was already full. Consistent with findings using the Sternberg paradigm with other materials (Abadie, & Camos, 2019; Coane et al., 2007; Melnik et al., 2017; see Festini & Katz, 2021, for the putative underlying mechanisms), we found that the presence of the probe was spotted faster than its absence.

Our results on emotions have been nonsignificant, except for an interaction that indicates that emotions differently modulated the number of false positive identifications committed by club players and experts. The subjective ratings indicate that the players did not feel the emotional influence of the inducers, which reflects the fact that the emotions induced by the IAPS images were not sufficiently strong to disturb the cognitive processing of expert chess players. Our interpretation is that experts might develop some form of immunity to low-intensity emotional responses, a proposal in line with our theory of expert intuition (Chassy & Gobet, 2011). In a nutshell, the theory proposes that templates develop on the basis of domain-specific chunks and the evaluation they provide dictates the emotional response of the player. Templates are thus encoding not only the type of problems that an expert is facing but also the emotional reaction that is associated with the problem. For example, a template encoding a situation where the solution is well established will be associated with a strong positive emotion. By contrast, a template associated with a situation that requires one to be precise in the calculations will be associated with a fear response to heighten the sense of danger. Because players' emotional response is dictated by the material, incidental emotions will have lessened effect. Hence, at an advanced stage of expertise acquisition, learners have developed a capacity to isolate incidental emotions to avoid that they damage their field of expertise unless a given threshold, yet to be determined, is reached. To obtain measurable effects, stronger emotions should be generated, but such an approach would also raise a number of ethical issues that we have deliberately avoided in our study. Further research into the topic should be carried out, the main difficulty being to generate emotional reactions that are strong enough to be felt by the participants while being within the ethical limits of psychological research.

There are a number of caveats that call for further research before definite conclusions can be drawn. First, all the players recruited had significant experience with tournament practice and thus our study does not allow us to draw conclusions about the first stages of expertise acquisition. It would be of interest to replicate our study with a sample of players in the early stages of chess learning, even before they enter tournament practice. Such an experiment would provide a better measure of how chunks improve performance and potentially provide information about the stage of expertise acquisition at which players learn to isolate emotional influences.

A second caveat that could be addressed in a future study is the limited range of memory spans we tested. We opted for span sizes that are close to the established limit of human visual working memory; that is, four items. Our results suggest that club and expert players might be able to complete the task with more items. Such a study would help in defining the maximum amount of information, organized as chess positions, that experts can hold at any one time. This consideration leads us to our last point. Our study used a relatively restricted range of Elo ratings. With the objective of being comparable to previous studies while ensuring that our sample was as homogeneous as possible, we selected players who were within a limited amount of standard deviation from the expert cut point of expertise (rating = 2000 Elo) and who all had experience in official games. Also, in line with most studies on chess players' memory, we used only one exposure time (i.e., 5 seconds). A future study using a much wider range of Elo ratings, and manipulating the exposure time would address two of the limits evoked earlier. First, it would make it possible to determine a potential limit for the maximum amount of information that templates can hold. For this, it would be necessary to recruit strong grandmasters and test the limit of their encoding capacity. Second, by manipulating the exposure time of the encoding phase, it should be possible to estimate the speed at which templates are transferred into working memory and relate the time of exposure to the number and type of errors, which in turn would provide an estimate of the time necessary to update the content of a template. Ideally, such an experiment would be carried out with an EEG to monitor the evoked response potentials that mark the recognition of the probe.

Finally, in spite of a heavy experimental paradigm, the analyses on trial number failed to find evidence of an effect of experimental fatigue on the participants' average performance or RT. Incidentally, we found the opposite effect: as the number of trials increased, the average response time decreased without any loss in performance. Considering the small amount of time gained per trial, as revealed by the equation, we would suggest interpreting this result as the consequence of the participants being increasingly familiar with the software used to collect data. In addition, the effect of this gain in time is cancelled out across different spans as the trials were randomized. Yet, experimental fatigue remains an interesting point to investigate. Future research, by drastically increasing the number of trials, could evaluate whether templates, by facilitating information processing of domain-specific material, reduce fatigue in experts.

To the best of our knowledge, this is the first study to use the Sternberg paradigm with expert chess players. By showing expertise effects on both reaction time and accuracy, it has paved the way for using the Sternberg task in exploring chess expertise. We have answered a few questions and hope that other teams will investigate the issues that were left unsolved in our study.

Endnote

1. In line with the chess literature, we use the terms "position" to indicate the locations of all the pieces on the 8 × 8 square matrix of a chessboard.

Authors' Declarations

The authors declare that there are no personal or financial conflicts of interest regarding the research in this article.

The authors declare that they conducted the research reported in this article in accordance with the Ethical Principles of the *Journal of Expertise*.

The dataset includes information from the players, thus providing it would breach the anonymity and confidentiality clause. The authors are happy to provide the preprocessed, anonymized datasets.

ORCID iDs

Philippe Chassy
https://orcid.org/0000-0001-8293-7064

Fernand Gobet
https://orcid.org/0000-0002-9317-6886

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Received: 15 August 2022
Revision received: 23 January 2023
Accepted: 9 February 2023

Appendix 1: N° of IAPS images

	Neutral			Negatives	
N°	**Valence**	**Arousal**	**N°**	**Valence**	**Arousal**
5390	5.59	2.88	1460	8.21	4.31
5510	5.15	2.82	1610	7.82	3.08
5720	6.31	2.79	1750	8.28	4.10
5731	5.39	2.74	1920	7.90	4.27
5740	5.21	2.59	2260	8.06	4.26
7000	5.00	2.42	2311	7.54	4.42
7004	5.04	2.00	5000	7.08	2.67
7006	4.88	2.33	5001	7.16	3.79
7010	4.94	1.76	5010	7.14	3.00
7020	4.97	2.17	5200	7.36	3.20
7025	4.63	2.71	5201	7.06	3.83
7030	4.69	2.99	5220	7.01	3.91
7031	4.52	2.03	5260	7.34	5.71
7035	4.98	2.66	5270	7.26	5.49
7040	4.69	2.69	5300	6.91	4.36
7041	4.99	2.60	5450	7.01	5.84
7050	4.93	2.75	5460	7.33	8.87
7060	4.43	2.55	5470	7.35	6.02
7080	5.27	2.32	5480	7.53	5.48
7090	5.19	2.61	5551	7.31	3.26
7100	5.24	2.89	5600	7.57	5.19
7110	4.55	2.27	5611	7.05	3.99
7140	5.50	2.92	5621	7.57	6.99
7150	4.72	2.61	5623	7.19	5.67
7161	4.98	2.98	5629	7.03	6.55
7175	4.97	1.72	5660	7.27	5.07
7179	5.06	2.88	5700	7.61	5.68
7185	4.97	2.64	5760	8.05	3.22
7187	5.07	2.30	5779	7.33	3.57
7205	5.56	2.93	5780	7.52	3.75
7217	4.82	2.43	5811	7.23	3.3
7224	4.45	2.81	5820	7.33	4.61
7233	5.09	2.77	5830	8.00	4.92
7234	4.23	2.96	5831	7.63	4.43
7235	4.96	2.83	8030	7.33	7.35
7490	5.52	2.42	8090	7.02	5.71
7491	4.82	2.39	8190	8.10	6.28
7700	4.25	2.95	8200	7.54	6.35
7705	4.77	2.65	8210	7.53	5.94
7950	4.94	2.28	8400	7.09	6.61