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Efficiency of the mnemonic system of expert soccer players under overload of the working memory in a simulated decision-making task

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ABSTRACT

Objectives: The study aimed at testing the efficiency of memory processes of expert soccer players under dual-tasks conditions involving a domain specific decision-making task and a secondary memorisation load.

Method: Twelve inexperienced and 12 expert soccer players were presented with a decision-making task based on the soccer-related situations (primary task) and an explicit memorisation task involving verbal and/or visuo-spatial material (secondary task). For the decision-making task, upon presentation of a soccer-related photograph on a computer screen, participants had to indicate which action they would undertake as the ball carrier (pass, keep or shoot). The same photographs appeared twice, according to the short-term priming repetition protocol. The explicit memorisation task involved memorisation and recognition of verbal and/or visuo-spatial items. Performance was recorded under single and dual-task conditions.

Results: There were no group-related differences in response accuracy or response time for the memorisation tasks. Regarding decision making, in inexperienced players, but not in experts, the priming effect on processing time depended on the nature of the memory task.

Conclusion: The pattern of results supports the idea of a practice induced adaptation of the functioning of the working memory. The experts appear to benefit from new, specific, memory and information processing resources, such as long-term working memory, enabling them to overcome the limitation of short-term working memory to treat domain specific information under high levels of time or load constraints.

Over the last three decades, research on expert performance has covered a wide variety of areas, including chess, physics, mathematics, medicine, music and sports (e.g., Ericsson, 2008). It is now established that not only the performance, but also the resources (e.g., specific knowledge vs. general knowledge) and processes (e.g. automatic vs. controlled) involved in this performance differ between experts and novices. In decision-making tasks, experts' performance relies on automatic processes based on knowledge that is specific to the expertise domain. It has been more recently demonstrated that the use of knowledge involves different modes of processing, from complex planning to automatic activation of perceptual knowledge (Laurent & Ripoll, 2009) and use of simple heuristics (Köppen & Raab, 2009). In familiar situations, decisions are fast and inexpensive for the attentional system. The aim of the present study was to assess the processes underlying decision making under conditions of working memory overload in expert soccer players.

According to Baddeley (2000, 2001a, 2001b, 2002) and Baddeley and Hitch (1974), working memory (WM) is a mnemonic system that processes and temporarily stores the information required for complex cognitive activities, such as comprehension, learning or problem-solving (see Andrade, 2001; Gaonac'h & Larigauderie, 2000, for reviews). It is hypothesized to be one of the limiting processes of cognitive functioning under conditions of overload (Baddeley, 2000, 2001a, 2001b, 2002; Baddeley & Hitch, 1974; Conway & Engle, 1994; Cowan, 1988; Daneman & Carpenter, 1980; Engle, Tuholski, Laughlin, & Conway, 1999; Just & Carpenter, 1992). According to Baddeley, WM involves four active components with

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limited capacities: a supervisory system called central executive, and three peripheral slave systems, the phonological loop, the visuo-spatial sketchpad and the episodic buffer. The central executive is the attentional component of the model. It is responsible for the selection and co-ordination of processing routines, as well as for making plans and selecting strategies. The phonological loop is thought to have developed based on processes initially evolved for verbal perception (the phonological store) and production (the articulatory rehearsal component) while the visuo-spatial sketchpad stores and manipulates spatial and visual information (such as image processing). The episodic buffer handles multidimensional information and plays a role of interface between the slave systems and the long-term memory. If Baddeley's model of WM can account for the mediocre problem-solving performance of novice subjects, the limited capacity of the WM system no longer seems to be an issue when it comes to expert performance (Tenenbaum, 2003, 2004; Tenenbaum, Tehan, Stewart, & Christensen, 1999).

Two hypotheses have therefore been put forward to explain exceptional expert performance in decision-making and memorisation tasks: (i) the knowledge-base hypothesis (Chase & Simon, 1973a, 1973b; Chi, 1978; Frey & Adesman, 1976; Garland & Barry, 1990, 1991; Glaser & Chi, 1988; Logan, 1988a, 1988b; Postal, 2004; Zoudji & Thon, 2003), and (ii) the skilled-memory hypothesis (Ericsson & Delaney, 1998, 1999; Ericsson & Kintsch, 1995, 2000; Postal, 2004; Zoudji & Thon, 2003).

The knowledge-base theory stipulates that practice enables experts not only to broaden their domain-specific knowledge store, but also to organize and structure it within long-term memory (LTM). For example, expert chess players have been shown to master between 50,000 (Gobet & Simon, 1996; Saariluoma, 1994; Simon & Gilmartin, 1973) and 300,000 chunks (Gobet & Simon, 2000), which are groupings of chess pieces that correspond to specific game patterns. Such chunks, which belong to perceptual discrimination networks, are stored in LTM and can be retrieved easily in order to recognize a problem situation (Gobet & Simon, 2000).

The skilled-memory theory describes how practice improves the efficiency of data encoding, storage, and retrieval processes of the various memory systems (Chase & Ericsson, 1982; Ericsson & Delaney, 1998, 1999; Ericsson & Kintsch, 1995, 2000; Ericsson & Lehmann, 1996). According to these authors, there exists a specific memory structure, the so-called long-term working memory (LTWM) that registers procedures as well as instructions for encoding, stocking and retrieving information directly from LTM (Ericsson, Delaney, Weaver, & Mahadevan, 2004; Ericsson & Kintsch, 1995; Ericsson & Lehmann, 1996; Ericsson, Patel, & Kintsch, 2000; Kintsch, Patel, & Ericsson, 1999). In other words, in their field of expertise, experts use part of the LTM as a WM, which increases storage capacity and speed of information processing and retrieval. In contrast, novices, who do not possess specific knowledge in LTM, are bound to rely on their WM to solve the situation. Unlike the WM model proposed by Baddeley and colleagues, the LTWM model implies that the available information required to solve a problem is not exclusively held in short-term buffers. The extent to which WM is required depends on whether specific knowledge is available or not in LTM, that is, on the level of expertise of the subject. In addition, experts appear to be able to take advantage of the organisation of domain specific knowledge in LTM to enhance accessibility of information in LTWM (Guida & Tardieu, 2005; Sohn & Doane, 2003; Tenenbaum et al., 1999). The idea that LTWM supplements short term working memory (STWM) in experts through the establishment of retrieval structures has received some support from experiments regarding decision making in sports (Tenenbaum, 2003, 2004).

The LTWM and knowledge-base hypotheses are not contradictory, insofar as the memory system and domain-specific knowledge-bases interact, working together to achieve high performance in memory and/or decision-making tasks. Indeed, with practice, experts acquire specific knowledge, thus increasing their knowledge store. High frequency use of this domain specific knowledge enables faster information encoding, storing, and retrieving, that is, the development of skilled memory. Hence, practice enables experts to acquire both the domain specific (declarative) knowledge and the procedures to make use of it (procedural knowledge) that are required to respond rapidly and efficiently to familiar situations. In addition, experts can develop storage and retrieval structures for functional units of knowledge, which, once activated, would enable an expansion of the WM capacity to deal with novel situations. Thus, thanks to the LTWM, experts could highly strategically retrieve information in LTM and activate it in WM. LTWM can be seen as a part of LTM that would be specialised in the encoding, storage and retrieval cues for the domain specific knowledge that has been used to solve a situation. Activation of such a retrieval structure would enable experts to activate all of the knowledge required to perform a given task at a low cost. It is important to note that LTWM is not an all purpose memory structure and can only be used for performing in the expertise domain. It acts as an expert interface to transfer information between working and long-term memories.

Implication of the LTWM in experts' decision-making has been confirmed in tasks relying on implicit memory processes (Poplu, Baratgin, Mavromatis, & Ripoll, 2003; Zoudji & Thon, 2003). Thus, within the domain of expertise, practice appears to promote not only an improvement of explicit memory processes, but also an increased efficiency of the automatic implicit memorisation processes. In the specific case of ball sports for example, players make use of memorised information without conscious evocation: they make decisions about actions to undertake without explicitly recalling past situations or memorised knowledge (Zoudji & Thon, 2003). In such open skills the environment constantly changes and decision-making is performed under great temporal constraints. Skilled performance can therefore not rest on slow deliberate processes. Automatic, implicit information processing appears better suited to allow the recording of the relevant multiple variables (Berry & Broadbent, 1988; Meulemans, 1998).

One can therefore hypothesise that experts will rely on the efficiency of their LTWM and implicit memory processes to solve problems in their domain of expertise, while inexperienced players will depend on reasoning processes engaging WM. Depending on the level of expertise of the performer, two types of cognitive processes would be called upon in problem-solving situations: automatic processes relying on links existing between memorised situations and actions in experts, and general, often declarative, knowledge and WM resources in the layman. One would therefore expect the processing costs to be greater and the efficiency of the response to be lesser in inexperienced players than in experts. In addition, when the WM is loaded with a concurrent task, experts should maintain a high level of performance, whereas the performance of novices should further decrease. Indeed, if Ericsson and Kintsch's (1995) are correct, expert subjects should be able to take advantage of their LTWM to process domain specific information, while the inexperienced players cannot. When an unrelated, non-domain specific, concurrent task is added both experts and inexperienced players rely on WM to process it. But because the experts rely on LTWM for the primary task, there should be less interference with the secondary task, and therefore performance should be less affected in experts than in inexperienced players who process the two tasks in WM.

In the present experiment, we evaluated the influence of verbal and visuo-spatial WM overloading on decision and memorisation performance in experts and inexperienced players in order to assess the mechanisms and resources underlying the functioning of the two groups. We used a short-term priming repetition protocol to access automatic decision-making processes. The short-term priming repetition paradigm consists in presenting identical priming and target stimuli pairs within a short time (50–5000 ms) interval. Short-term priming is thought to facilitate the processing of the target information when the situation is repeated, leading to an improvement of decision-making time (Lebreton, Desgranges, Baron, & Eustache, 1999; Scarborough, Cortese, & Scarborough, 1977; Scarborough, Gerard, & Cortese, 1979) and response accuracy (Lebreton et al., 1999).

Using a pre-loading technique and a dual-task protocol, we measured the influence of a verbal or visuo-spatial secondary task on the short-term priming repetition effect occurring between two presentations of the same soccer situation in expert and inexperienced soccer players. We hypothesized that the decision-making performance of the expert soccer players would be less influenced than that of the inexperienced players by the interfering non-domain specific memorisation task.

Method

The experimental design included a domain specific decision-making primary task and non-specific memorisation secondary tasks. There were five experimental conditions: three single tasks and two double tasks. The three single tasks were two memorisation (recognition) tasks, one for verbal items and one for visuo-spatial items, and one decision-making task. Regarding the double tasks, participants were required to memorise either verbal or visuo-spatial items while making decisions on soccer pictures.

Participants

Two groups of 12 inexperienced control (INE) and 12 expert (EXP) male soccer players participated in the experiment. The control participants (M age = 22, SD = 2.13) had never practiced team sports in a club and only participated in occasional soccer games in physical education classes or with friends. The experts (M age = 22, SD = 3.09) were all professional soccer players who had been playing on a top-level team engaged in national competition. They had been playing soccer for an average of 14.8 years (SD = 3.7) with a mean of 420 match competitions (SD = 66) and trained or played for an average of 11.4 h (SD = 3.6) per week. None of the subjects had ever taken part in the present type of experiment. In addition, participants who used to play videogames related to team ball sports (eg, Fifa, Pro-Soccer Evolution, or any equivalent games) were excluded. The participants volunteered to participate and provided informed consent. The experiment was approved by the local ethic committee.

Experimental material

The experiment was conducted using a Macintosh computer with a 17-inch LCD screen with a refresh rate of 8 ms. The SuperLab™ software was used to present the stimuli and record the data. This software provides response times with an accuracy of 1 ms.

Three types of stimuli were used: photographs of soccer-related situations for the decision-making task, and lists of five words and spatial configurations of five black dots arranged on a 25-cell grid for the memorisation tasks.

Photographs of soccer-related situations

A total of 114 pictures selected from an initial set of 300 soccer situations recorded on video tape during simulated matches were used for the experiment. As described previously (Zoudji & Thon, 2003), these images were digitised and stored on computer files. All pictures were recorded from the same position, 2 m above the ground and 30 m in front of the goal. The pictures were 11 cm high and 15 cm wide, covering a viewing angle of 0°, when displayed on the computer screen. Each picture depicted offensive soccer plays involving two offense players including a ball carrier against three defence players (including the goalkeeper), or three offense players against three defence players. The ball was always clearly visible. Offensive players wore red shirts, and defenders wore green shirts. For each play, there was an optimal action for the ball carrier to undertake (pass to a team-mate, keep the ball, or shoot at the goal). The optimal action had been determined as in Helsen and Starkes (1999). Specifically, 10 semi-professional coaches who did not participate in the experiment were asked to examine the initial pool of pictures and determine the situations for which there was only one optimal offensive move. Only photographs leading to 100% agreement across coaches were selected as test stimuli.

Ninety-six of these pictures were used for the decision-making trials: 48 for the control single task condition, 24 for the verbal double task condition, and 24 for the visuo-spatial double task condition. The remaining eighteen pictures were used for the familiarisation trials presented prior to each condition.

Lists of words

Forty-eight pairs of lists of 5 monosyllabic words were constructed based on the material of Fayol and Got (1991) and Ganier (1999). The words belonged to various semantic categories (places, food, objects, animals, etc.), and had phonological rhyme similarities in order to increase the solicitation of the phonological loop for information storage and retrieval. Of the 48 pairs of lists, 24 pairs were identical and 24 differed by two words that were randomly positioned in the list. One set of 24 pairs (12 identical, 12 different) was used in the single task, the other set in the double task.

Spatial configurations of black dots arranged on a 25-cell grid

Similarly, 48 pairs of 5-dots spatial configurations were constructed (Ganier, 1999; Kruley, Sciama, & Glenberg, 1994). The 5 dots were arranged on a 25-cell grid (5 rows by 5 columns). Twenty-four of the 48 pairs of spatial configurations were identical, while the other 24 configurations were different. One set of 24 pairs (12 identical, 12 different) was used in the single task, the other set in the double task.

Prior control experiments

Recognition tests were carried out prior to the main experiment in order to validate the items (lists and dot patterns) and durations of display to be used for the memorisation tasks. According to Ganier (1999) durations of display of 3000 ms for the word lists, and 2000 ms for the dot patterns enable a successful recognition rate of 90–95%, ensuring equivalent cognitive loads for the two types of items. The delay between acquisition and recognition was set at 3000 ms, as it needed to be kept constant under the single and double task conditions of the main experiment. This duration was chosen after preliminary experiments had shown that the response times of experts soccer players in the decision-making task ranged between 800 and 2000 ms.

In the control experiments, the list of words (for the verbal memorisation task) or dot patterns (for the visuo-spatial memorisation task) were presented to a group of 12 Sports Sciences students (M age = 23, SD = 1.5) who did not participate in the main experiment. Participants were requested to explicitly memorise the items presented on the computer screen (for 3000 ms for the verbal items, and 2000 ms for the visuo-spatial ones). After a 3000 ms delay, they were presented with a new list or dot pattern and asked whether it was identical or different from the memorised one.

Prior to the main experiment, the participants were given a practice session (36 decision-making trials) to familiarize them with the experimental procedure and practice the link between the fingers and keys assigned to the responses (Zoudji & Thon, 2003). The pictures used for these trials were not used in the main experiment.

Experimental design

The main experiment included two tasks: a decision-making task based on the soccer-related situations (primary task) and an explicit recognition task involving the verbal and visuo-spatial material (secondary or interference task).

A short-term priming repetition protocol was used for the decision-making task in order to tap on domain specific implicit processes. Upon presentation of a soccer-related photograph on the computer screen, participants were required to indicate which action they would undertake if they were the ball carrier. They were instructed to respond as correctly and as fast as possible, by pressing on the key assigned to that response on the computer's keyboard. Each decision-making experimental block started with three familiarisation trials.

The explicit memorisation task involved two modalities: memorisation of verbal items and memorisation of visuo-spatial items. In the verbal memorisation task, the participant was explicitly asked to memorise the list of 5 words visually presented on the screen. In the visuo-spatial memorisation task, the participant was to retain the 5-dot spatial configuration presented on the 25-cell grid. After a delay of about 3000 ms that was either free or filled by the primary decision-making task, a new list of words or a spatial configuration, identical to, or different from, the previous one, was shown. The participant was requested to press the key associated with the correct response: identical or different. The rationale was that the 5-word lists would load the phonological loop while the 5-dot spatial patterns would call upon the visuo-spatial sketchpad.

Procedure

Each participant was tested individually. Participants sat in front of a computer screen on which the items (verbal or visuo-spatial) and/or photographs, depending on the experimental condition, were presented.

The experimental design included five conditions; three control single task conditions and two dual-task conditions (see Fig. 1). The order of the conditions was counterbalanced between subjects. However, in order to prevent the participants from noticing that soccer pictures tended to be presented twice and understanding that their memory for soccer situations was being tested, the simple decision-making task was always delivered last and included catch trials.

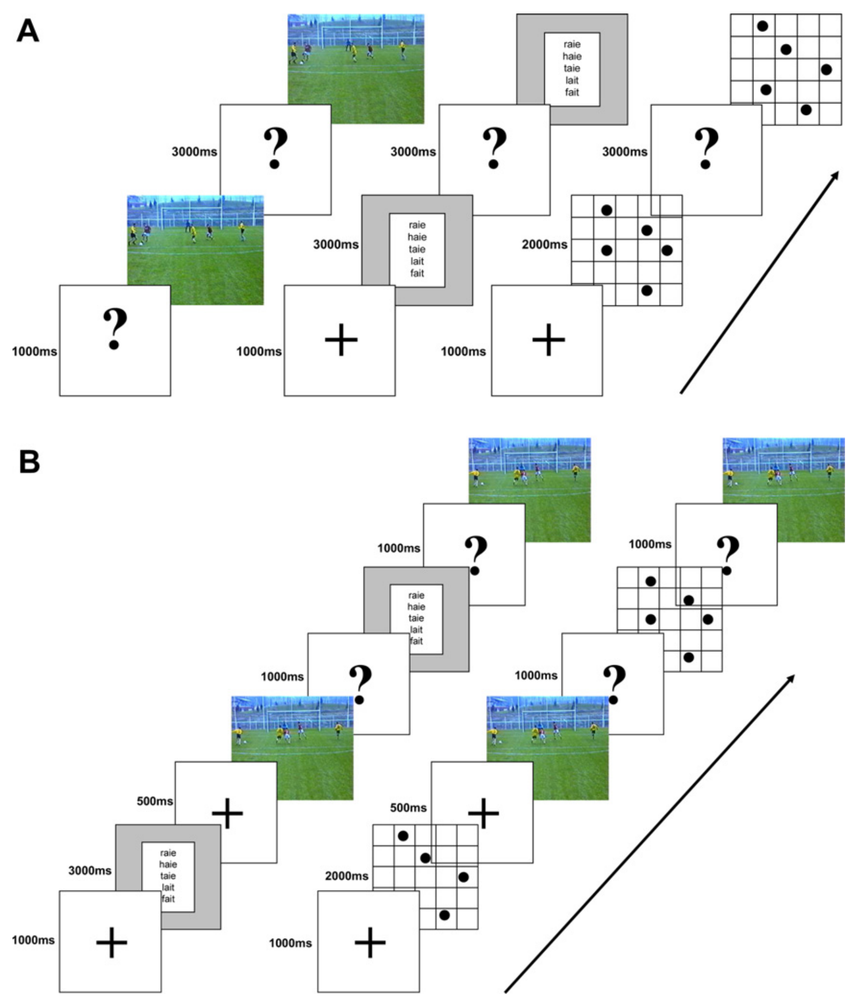

Fig. 1. Schematic representation of the experimental procedure, showing, from front to back the sequence of stimuli appearing on the screen. (A) Single task condition for the decision making task (left), verbal memorisation task (middle) and visuo-spatial memorisation task (right). (B) Dual task conditions: memorisation of verbal items and decision-making (left), memorisation of visuo-spatial items and decision-making (right). See text for details. The arrow indicates time.

Single tasks

The three single tasks, memorisation of verbal items, memorisation of visuo-spatial items, and simple decision-making, provided control data.

For the memorisation tasks, each trial began with the display of the "+" symbol in the middle of the screen for 1000 ms, followed by the presentation (3000 ms in the verbal memorisation task, and 2000 ms in the visuo-spatial task) of the item to be memorised. After a 3000 ms delay where the "?" symbol reappeared on the screen, a new item was displayed. The participant had to decide as correctly and as fast as possible if it was identical to, or different from, the memorised one.

In the decision-making task, the trial began with the display of the "?" symbol in the middle of the screen for 1000 ms, followed by a photograph of a soccer-related situation. The image stayed on the screen until the key corresponding to the chosen action was pressed. The "?" symbol then reappeared on the screen for 3000 ms, followed by the photograph of the soccer-related situation which remained until the participant had responded. The order of presentation of the different photograph pairs was random. The single decision-making task included 24 repetition priming and 24 catch trials.

Dual tasks

The two dual tasks involved memorisation of verbal items and decision-making, and memorisation of visuo-spatial items and decision-making under a pre-loading protocol.

For each trial, a "+" symbol appeared on the screen for 1000 ms, followed by the presentation (3000 ms for the word lists, 2000 ms for the dot patterns) of the item to be memorised. It was replaced by the "+" symbol for 500 ms, followed by the display of a soccer-related situation which stayed on the screen until the participant responded. The "?" symbol reappeared on the screen for 1000 ms. The recognition item was then displayed, and the participant was to respond as quickly as possible. The "?" symbol returned for 1000 ms, followed by the second presentation of the soccer-related situation. The participant was asked again to choose the best response as fast as possible. Each experimental block included 24 trials.

Data collection and statistical analysis

For the memorisation (interference) tasks, response time (RT) and response accuracy (RA) were the dependant variables. Regarding the decision-making (primary) task, three dependent variables were analysed: RT, RA, and response consistency (RC). RT was defined as the time elapsed between the onset of stimulus presentation and the participant's key-press response. For RA, one point was awarded if the subject chose the action defined as optimal by the semi-professional coaches, zero point if he chose another action. Regarding RC, one point was awarded if the participant gave the same response for the first and second presentation of the same situation.

Individual means and standard deviations were first computed for each of the dependent variables. After verifying that the assumptions for parametric tests (homoscedasticity using Levene's test and normality of distributions using Kolmogorov–Smirnov) were not violated, the individual means were compared using analyses of variance (ANOVA).

Regarding the memorisation tasks, the ANOVA design was a 2 "Group" (expert, EXP, inexperienced players, INE) × 2 "Condition" (single, dual) × 2 "Item Type" (verbal, visuo-spatial) with repeated measures on the two last factors. For the decision-making tasks, the designs were a 2 "Group" (EXP, INE) × 2 "Presentation" (first, second) × 3 "Condition" (single task, verbal dual task, visuo-spatial dual task) with repeated measures on the two last factors for RT, and a 2 "Group" (EXP, INE) × 3 "Condition" (single task, verbal dual task, visuo-spatial dual task) with repeated measures on the last factor for RA and RC. Post-hoc Newman–Keuls comparisons were used to determine the source of any significant effects. The alpha level for significance was set at $p < .05$. Bonferroni corrections for multiple comparisons were applied when required. Effect sizes are reported as Wilks' Lambda (Wilks' Λ) coefficients for the multivariate effects, and Cohen's mean standardized differences (ES) for post-hoc comparisons.

Results

Memorisation tasks

Response accuracy

There was no significant difference in response accuracy between the two groups *Wilks'*$\Lambda = 0.91$, $F(1,22) = 1.297$; *ns*. The average score was 0.81 ± 0.01 for INE and 0.79 ± 0.01 for EXP. The "Condition" factor yielded a significant effect *Wilks'*$\Lambda = 0.41$, $F(1,22) = 84.90$; $p < .0001$, as did "item type" *Wilks'* $\Lambda = 0.45$, $F(1,22) = 9.65$; $p < .005$ (see Table 1). The mean score of correct answers was greater under the single task conditions than under the dual task ones (single task: 0.88 ± 0.04, dual task: 0.72 ± 0.06), and greater for the verbal items (0.84 ± 0.05) than for the visuo-spatial items (0.77 ± 0.06). Interactions were non-significant.

Response time

The effect for "Group" on response time was non-significant *Wilks'* $\Lambda = 0.92$, $F(1,22) = 1.08$; *ns*. The average response time was 2034 ± 61 ms for INE, and 2155 ± 55 ms for EXP. The analysis revealed a significant difference between the single and dual-tasks conditions *Wilks'* $\Lambda = 0.55$, $F(1,22) = 37.9$; $p < .0001$, with shorter response times under the single task condition than under the dual task one (single task: 1893 ± 158 ms; dual task: 2296 ± 191 ms). In addition, there was a significant effect for the "Item Type" factor *Wilks'* $\Lambda = 0.48$, $F(1,22) = 88.6$; $p < .0001$. Response time was shorter for the visuo-spatial items than for the verbal ones (1606 ± 134 ms vs. 2583 ± 215 ms). Interactions were not significant.

Decision-making task

We first verified that catch trials fulfilled their purpose, comparing RT and RA between catch trials and repetition priming trials. Whether for RT or RA, there were no differences between catch trials and the first presentation of the repetition priming trials. In contrast RT, but not RA, differed between catch trials and the second presentation of the repetition priming trials. In both groups, RT was longer for catch trials than for the second presentation of the repetition priming pictures (INE: catch trials 2643 ms, first presentation 2460 ms, second presentation 1169 ms; EXP: catch trials 2340 ms, first presentation 2148 ms, second presentation 972 ms). In addition, participants did not report noticing that the pictures were presented twice.

Table 1
Response accuracy (mean ± standard deviation) on the memorisation task for the two groups of participants under each experimental condition.

	Single task		Dual task	
	Verbal	Visuo-Spatial	Verbal	Visuo-Spatial
Inexperienced	0.93 ± 0.05	0.89 ± 0.1	0.78 ± 0.16	0.68 ± 0.08
Mean	0.91 ± 0.08		0.73 ± 0.14	
Expert	0.89 ± 0.09	0.83 ± 0.09	0.77 ± 0.12	0.67 ± 0.12
Mean	0.86 ± 0.09		0.72 ± 0.13	

Response accuracy

Analysis revealed a significant effect for the "Group" factor *Wilks' Λ* = 0.30, $F(1,22) = 12.35$; $p < .002$; (ES = 0.8). The experts had an average rate of correct responses of 0.72 ± 0.10, while the inexperienced players had an average score of 0.59 ± 0.18. Thus, the two groups performed above chance level (0.33) (INE: test $t = 1{,}96$, dl = 11, $p = .001$, Effect Size = 0.84). The effect for the "Condition" factor (*Wilks' Λ* = 0.82, $F(2,44) = 1.45$; *ns*) and the "Group" by "Condition" interaction were not significant. In the two groups, RA slightly decreased under the visuo-spatial dual condition (INE: 0.55 ± 0.09; EXP: 0.69 ± 0.09).

Response consistency

For this variable, the effect for the "Group" factor was close to significance *Wilks' Λ* = 0.57, $F(1,22) = 9.19$; $p < .01$; ES = 0.30. The responses of the experts were the most consistent, with an average consistency rate of 0.91 ± 0.09, while the average rate for the inexperienced players was 0.80 ± 0.14. The effect of the "condition" factor was non-significant (*Wilks' Λ* = 0.89, $F(2,44) = 2.002$; *ns*), as were the interactions.

Response time

Analysis revealed significant effects of "Presentation" *Wilks' Λ* = 0.23, $F(1,22) = 70.13$; $p < .0001$ and "Condition" *Wilks' Λ* = 0.39, $F(2,44) = 13.54$; $p < .0001$, as well as a significant interaction between these two factors $F(2,44) = 11.80$; $p < .0001$. In addition, although the main effect for "Group" was not significant, the ANOVA revealed a three-way interaction between the "Group", "Presentation" and "Condition" factors *Wilks' Λ* = 0.57, $F(2,44) = 2.44$; $p < .006$.

Overall, RTs were shorter following the second presentation of the soccer-related situation than following the first presentation, the gain being greater under the single than under the dual-task conditions. Decomposition of the interactions revealed that, following the first presentation of the soccer picture, RT was similar under single and dual-task conditions in the inexperienced players, but not in the experts. In experts, the increase in RT from single task to visuo-spatial dual-task condition was significant ($p < .001$; ES = 0.50); the difference between single and verbal dual condition fell short of significance ($p < .008$; ES = 0.70). More importantly, while in experts RT to the second presentation was always significantly shorter than RT to the first presentation (single task: $p < .0002$; ES = 1.4; verbal dual task: $p < .0002$; ES = 1.1; visuo-spatial dual task: $p < .0002$; ES = 1.1), in inexperienced players, the gain in RT depended on the experimental condition, decreasing from the single ($p < .0002$, ES = 1.2) to the verbal dual ($p < .0002$, ES = 0.6) to the visuo-spatial dual task (*ns*, ES = 0.4). In other words, while priming was independent on the experimental condition in experts, this was not the case in INE (see Fig. 2).

Discussion

The aim of this study was to assess the processes underlying decision making under conditions of working memory overload in expert soccer players. We hypothesized that experts would be less affected than inexperienced players under these conditions. The results partly support our hypothesis. Before discussing the performances of the two groups in the decision-making tasks and the influence of expertise on the priming effects, we will examine the results of the control tasks.

Methodological choices

As expected, analyses revealed that the performance of the two groups of participants was less accurate under the dual-task conditions than that under the single task ones. This was mainly true for the memorisation task, while the decrease in accuracy was not statistically significant for the decision-making task. In addition, response time increased under dual-task conditions. Such a negative effect is in agreement with the well documented functional limitation of the STWM under dual-task conditions (Baddeley, 2000, 2001a, 2001b, 2002; Baddeley & Hitch, 1974; Conway & Engle, 1994; Cowan, 1988; Daneman & Carpenter, 1980; Engle et al., 1999; Just & Carpenter, 1992). Indeed, the decrease in performance is most likely due to the additional processing load imposed under the dual-task condition, attentional resources being necessary both for maintaining items in the appropriate sub-system and for processing the soccer-related decision-making with the help of these sub-systems. In addition, in experts, but not in inexperienced players, RT to the decision making task also increased under dual-task condition following the first presentation of the situation. This is in agreement with the results of Beilock and colleagues (Beilock & Carr, 2005; Beilock, Kulp, Holt, & Carr, 2004) regarding choking of performance under pressure. These authors reported a decrement

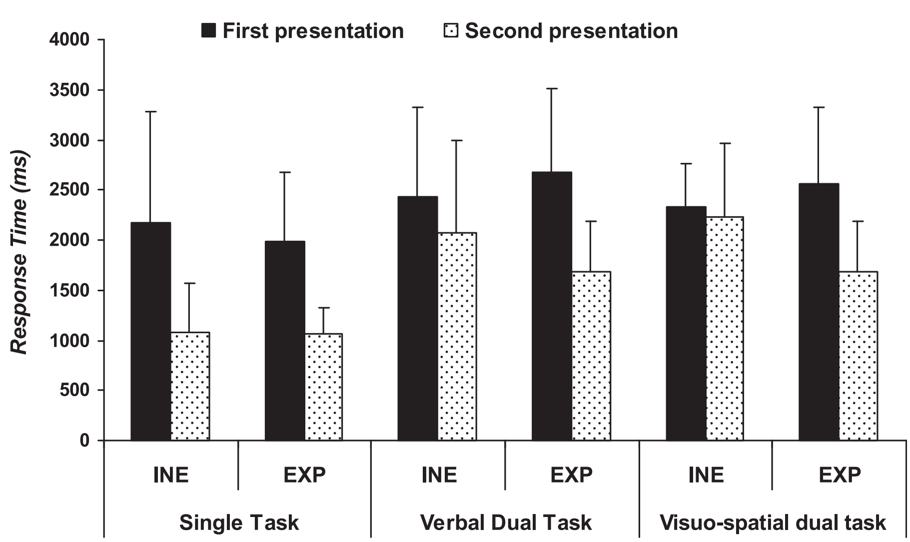

Fig. 2. Response time in the decision making task for the two groups of participants and under the three experimental conditions. INE: inexperienced players; EXP: expert players; *denotes significant differences between the first and second presentation of the soccer-related presentation.

in expert performance when the WM capacity available for skill execution is reduced. They concluded that if the ability of WM to maintain information with immediate relevance to the task is disrupted, performance may suffer. Thus, these results confirm that the dual-task procedure was effective in perturbing the functioning of the WM. In contrast, in inexperienced players, following the first presentation of the soccer-related situation, the dual-task conditions only influenced response time for the memorisation task and not for the decision-making one. A possible explanation of such an asymmetry of the dual-task influence following the first presentation of the soccer-related situation is that these participants set a priority for the primary decision-making task over the secondary memorisation one.

The results for the visuo-spatial and verbal memorisation tasks did not reveal any difference in response accuracy nor response time between the two groups. In other words, as expected, the ability to memorise non soccer-related word lists or visuo-spatial patterns was independent on the level of expertise in soccer. These results are in agreement with those of previous studies (Binet, 1892, 1893; Schneider, Gruber, Gold, & Opwis, 1993), and confirm that experts do not possess enhanced memory skills outside their field of expertise. We can thus assume that the two groups of participants were involved in the same explicit memorisation process during these tasks. Differences between experts and inexperienced players in the decision-making task related to soccer will therefore not be attributable to differences in the general mnemonic capacities of the two groups.

Decision-making (primary) task

As expected from the criteria used to select the participants, the experts' accuracy scores on the decision-making task were significantly greater than that of the inexperienced players. In addition, experts were also more consistent than inexperienced players in their responses, indicating that they did not provide random answers to the soccer-related situations. This result is in agreement with the prediction of Glencross, Whiting, and Abernethy (1994) that expert performance should be regular and stable over time, as well as adaptable to contextual variations. However, it is also important to stress that the rate of correct responses of the inexperienced participants exceeded chance level, and that they were quite consistent in their decision, showing that they did comply with the requirements of the experimental design. This may have been made easier by the fact that the soccer pictures used in the experiments only involved a small number of players, that is, were the simplest situations one can encounter in the game. Although this choice may somewhat preclude generalisation of the results to highly complex game situation, it made it possible for the inexperienced players to comply with the requirements of the task. In addition, Zoudji and Thon (2003) used a variety of soccer situations including a greater number of players in the field, in a former decision-making experiment. Their results showed that the complexity of the situation did not statistically influence RA or RT.

Expertise and priming effects

The focus of the present experiment was the issue of memory processes in experts. Our results revealed significant short-term priming effects in this group, under the single as well as under the two dual-task conditions. In contrast, in inexperienced players, the improvement in the time needed to make a decision following the second presentation of the soccer-related situation depended on the presence and nature of the dual task.

Single task condition

Under this condition, the two groups displayed similar gains in performance following the second presentation of the soccer situation. This effect resembles a recency effect. Indeed, because of the short delay intervening between the first and second presentation of the decision-making situation, the relevant information is still present in WM when the picture appears the second time. According to Cuddy and Jacoby (1982), Jacoby (1978), when the solution to a problem is already present in WM, the response time is shorter as the solving processes does not need to unfold to access the solution. Thus, when the soccer situation returns, the gain in response time is similar in the two groups, as the processes involved are the same.

Dual task

In contrast to the single decision-making task, when participants are required to hold unrelated information into WM while making their decision on the soccer situation, the two groups did not appear to function similarly. In the group of inexperienced players, the short-term priming effect observed under the single task condition was reduced, but somewhat preserved, under the verbal dual-task condition (when the phonological loop is required to hold the list of words in WM). It disappeared altogether under the visuo-spatial dual-task condition (that is, when the visuo-spatial sketchpad was engaged to hold the dot pattern). The experts clearly outperformed the inexperienced players under these two dual-task conditions. In fact, in expert, the priming effect remained identical whether or not the WM was loaded with unrelated information. Thus, the secondary tasks did not interact with the priming effect in a similar way in the inexperienced players and in the experts. This pattern of results suggests that under dual-task conditions the two groups rely on different processing mechanisms to resolve the task.

What are the mechanisms enabling the expert to access the response in LTM on the basis of a limited number of cues? One first hypothesis is that, whatever the condition, when a soccer-related situation is processed the first time, it is (or the response is) somehow stored and tagged in LTM (Ericsson, 2004; Ericsson & Kintsch, 1995). If the same situation presents itself anew, the initial processing does not need to be completed, as the expert LTWM can retrieve it efficiently and rapidly, thanks to the associated cues. These structured retrieval cues enable the efficient recovery of information even under condition of overload of the WM. In addition, according to Ericsson and Kintsch (1995), experts have developed the ability to use part of their LTM as a WM, the so-called LTWM, when they perform in their field of expertise, thus extending their WM capacity. This idea has received support from a number of studies (e.g., Masunaga & Horn, 2000; Sohn & Doane, 2003; Tenenbaum et al., 1999). Thus, in the present experiment, when the soccer picture appears again under dual-task conditions, experts would not need to process it in STWM, thus limiting interference with the memorisation, whether of verbal or visuo-spatial items.

Inexperienced players, on the other hand, keep depending on WM processing when a given situation appears again. Indeed, one observes a gain in response time when the WM is fully available, but not when the memorisation tasks taps on the same processing resources as the decision-making task, as is the case in the visuo-spatial dual task. Interestingly, when the memorisation task involved phonological rather than visuo-spatial processing, a short-term priming effect was still present in the inexperienced players. This difference between the two dual-task conditions suggests that, under the verbal dual-task condition, the inexperienced participants were able to process the memorisation task using the phonological loop of the WM, and the decision-making using the visuo-spatial sketchpad. Such a mechanism could explain the limited interferences between the two tasks, as they do not depend on the same processing resources.

Overall, our results are congruent with the idea of a practice induced adaptation of the WM functioning. We favour the idea that experts benefit from the emergence of new, specific memory and information processing skills. LTWM could underlie, at least partly, such expert information processing skills, enabling the experts to surpass the processing capacity of short-term working memory to treat domain specific information under high levels of time or load constraints.

References

Andrade, J. (2001). An introduction to working memory. In J. Andrade (Ed.), *Working memory in perspectives* (pp. 3–30). Hove/New York: Psychology Press.

Baddeley, A. D. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*, 417–423.

Baddeley, A. D. (2001a). Levels of working memory. In M. Naveh-Benjamin, M. Moscovitch, & H. L. Roediger (Eds.), *Perspectives on human memory and cognitive ageing: Essays in honor of Fergus Craik* (pp. 111–123). New York: Psychology Press.

Baddeley, A. D. (2001b). Comment on Cowan: the magic number and the episodic buffer. *Behavioral and Brain Sciences, 24*, 117–118.

Baddeley, A. D. (2002). Is working memory still working? *European Psychologist, 7*(No. 2), 85–97.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *The psychology learning and motivation, Vol. 8* (pp. 47–89). New York: Academic Press.

Beilock, S. L., & Carr, T. H. (2005). When high-powered people fail: working memory and "choking under pressure" in math. *Psychological Science, 16*, 101–105.

Beilock, S. L., Kulp, C. A., Holt, L. E., & Carr, T. H. (2004). More on the fragility of performance: choking under pressure in mathematical problem solving. *Journal of Experimental Psychology: General, 133*(4), 584–600.

Berry, D. C., & Broadbent, D. E. (1988). Interactive tasks and the implicit-explicit distinction. *British Journal of Psychology, 79*, 251–272.

Binet, A. (1892). Le calculateur Jacques Inaudi. *Revue des deux Mondes, 111*, 905–924.

Binet, A. (1893). Les grandes mémoires: Résumé d'une enquête sur les joueurs d'échecs. *Revue des deux Mondes, 117*, 826–859.

Chase, W. G., & Ericsson, K. A. (1982). Skill and working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation, Vol. 16* (pp. 1–58). New York: Academic Press.

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

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

Chi, M. T. H. (1978). Knowledge structures and memory development. In R. Singler (Ed.), *Children's thinking: What develops?* (pp. 73–96). Hillsdale, NJ: Erlbaum.

Conway, A. R. A., & Engle, R. W. (1994). Working memory and retrieval: a resource-dependent inhibition model. *Journal of Experimental Psychology: General, 123*, 354–373.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin, 104*, 163–191.

Cuddy, L. J., & Jacoby, L. L. (1982). When forgetting helps memory: an analysis of repetition effects. *Journal of Verbal Learning and Verbal Behavior, 21*, 451–467.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450–466.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: a latent variable approach. *Journal of Experimental Psychology: General, 125*, 309–331.

Ericsson, K. A. (2004). Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Academic Medecine, 79*(N 10), 70–81.

Ericsson, K. A. (2008). Deliberate practice and acquisition of expert performance: a general overview. *Academic Emergency Medicine, 15*(11), 988–994.

Ericsson, K. A., & Delaney, P. F. (1998). Working memory and expert performance. In R. H. Logie, & K. J. Gilhooly (Eds.), *Working memory and thinking* (pp. 93–114). Hillsdale, NJ: Erlbaum.

Ericsson, K. A., & Delaney, P. F. (1999). Long-term working memory as an alternative to capacity models of working memory in everyday skilled performance. In A. Miyake, & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 257–297). Cambridge, UK: Cambridge University Press.

Ericsson, K. A., Delaney, P. F., Weaver, G., & Mahadevan, R. (2004). Uncovering the structure of a memorist's superior "basic" memory capacity. *Cognitive Psychology, 49*, 191–237.

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

Ericsson, K. A., & Kintsch, W. (2000). Shortcomings of generic retrieval structures with slots of the type that Gobet (1993) proposed and model. *British Journal of Psychology, 91*, 571–588.

Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: evidence on maximal adaptations on task constraints. *Annual Review of Psychology, 47*, 273–305.

Ericsson, K. A., Patel, V. L., & Kintsch, W. (2000). How experts' adaptations to representative task demands account for the expertise effect in memory recall: comment on Vicente and Wang (1998). *Psychological Review, 107*, 578–592.

Fayol, M., & Got, C. (1991). Automatisme et contrôle dans la production écrite: les erreurs d'accord sujet-verbe chez l'enfant et l'adulte. *Année Psychologique, 91*, 187–205.

Frey, P. W., & Adesman, P. (1976). Recall memory for visually presented chess positions. *Memory and Cognition, 4*, 541–547.

Ganier, F. (1999). Le traitement cognitif: Déterminant de la conception de documents procéduraux (le cas des guides d'utilisation SEB), Bourgogne, Thèse de Doctorat.

Gaonac'h, D., & Larigauderie, P. (2000). *Mémoire et fonctionnement cognitif: la mémoire de travail*. Paris: Armand Colin.

Garland, D. J., & Barry, J. R. (1990). Sport expertise: the cognitive advantage. *Perceptual and Motor Skills, 70*, 1299–1314.

Garland, D. J., & Barry, J. R. (1991). Cognitive advantage in sport: the nature of perceptual structures. *American Journal of Psychology, 104*, 211–228.

Glaser, R., & Chi, M. T. H. (1988). Overview. In M. T. H. Chi, R. Glaser, & M. J. Farr (Eds.), *The nature of expertise* (pp. 15–28). Hillsdall, NJ: Erlbaum.

Glencross, D. J., Whiting, H. T. A., & Abernethy, B. (1994). Motor control, motor learning and the acquisition of skill: historical trends and future direction. *International Journal of Sport Psychology, 25*, 32–52.

Gobet, F., & Simon, H. A. (1996). Recall of random and distorted chess positions: implications for the theory of expertise. *Memory and Cognition, 24*, 493–503.

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

Guida, A., & Tardieu, H. (2005). Is personalisation a way to operationalise long-term working memory? *Current Psychology Letters: Behaviour, Brain and Cognition, 15*(1).

Helsen, W. F., & Starkes, J. L. (1999). A multidimensional approach to skilled perception and performance in sport. *Applied Cognitive Psychology, 13*, 1–27.

Jacoby, L. L. (1978). On interpreting the effects of repetition: solving a problem versus remembering a solution. *Journal of Verbal Learning and Verbal Behavior, 23*, 553–568.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: individual differences in working memory. *Psychological Review, 99*, 122–149.

Kintsch, W., Patel, V., & Ericsson, K. A. (1999). The role of long-term working memory in text comprehension. *Psychologia, 42*, 186–198.

Köppen, J., & Raab, M. (2009). Knowledge of athletes as cues for simple choices. In D. Araujo, H. Ripoll, & M. Raab (Eds.), *Perspectives on cognition and action in sport*. New York: Nova Science Publishers, INC.

Kruley, P., Sciama, S. C., & Glenberg, A. M. (1994). On-line processing of textual illustrations in the visuospatial sketchpad: evidence from dual-task studies. *Memory and Cognition, 22*, 261–272.

Laurent, E., & Ripoll, H. (2009). Extending the rather unnoticed Gibsonian view that 'perception is cognitive': development of the enactive approach to perceptual-cognitive expertise. In D. Araujo, H. Ripoll, & M. Raab (Eds.), *Perspectives on cognition and action in sport*. New York: Nova Science Publishers, INC.

Lebreton, K., Desgranges, B., Baron, J.-C., & Eustache, F. (1999). Les composantes structurales de la mémoire implicite: Neuroanatomie fonctionnelle des effets d'amorçage perceptif et sémantique. *Actes du Congrès National de la Société Française de Psychologie, Aix-en-Provence*25–27, mai.

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

Logan, G. D. (1988b). Automaticity, resources, and memory: theoretical controversies and practical implications. *Human Factors, 30*, 583–598.

Masunaga, H., & Horn, J. L. (2000). On the emergence of wisdom: expertise development. In W. S. Brown (ed), *Understanding wisdom: Sources, science & society* pp. 245–276.

Meulemans, T. (1998). Apprentissage implicite, mémoire implicite et développement. *Psychologie Française, 43*(1), 27–38.

Poplu, G., Baratgin, J., Mavromatis, S., & Ripoll, H. (2003). What kinds of processes underlie decision-making in soccer simulation? An implicit memory test. *International Journal of Sport and Exercise Psychology, 1*(4), 390–405.

Postal, V. (2004). Expertise in cognitive psychology: testing the hypothesis of long-term working memory in a study of soccer players. *Perceptual and Motor Skills, 99*, 403–419.

Saariluoma, P. (1994). Location coding in chess. *The Quarterly Journal of Experimental Psychology, 47A*, 607–630.

Scarborough, D. L., Cortese, C., & Scarborough, H. S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 1–17.

Scarborough, D. L., Gerard, L., & Cortese, C. (1979). Accessing lexical memory: the transfer of word repetition effects across task and modality. *Memory and Cognition, 7*, 3–12.

Schneider, W., Gruber, H., Gold, A., & Opwis, K. (1993). Chess expertise and memory for chess position in children and adults. *Journal of Experimental Child Psychology, 56*, 328–349.

Simon, H. A., & Gilmartin, K. J. (1973). A simulation of memory for chess positions. *Cognitive Psychology, 5*, 29–46, 1.

Sohn, Y. W., & Doane, S. M. (2003). Roles of working memory capacity and long-term working memory skill in complex task performance. *Memory and Cognition, 31*(3), 458–466.

Tenenbaum, G. (2003). Expert athletes: an integrated approach to decision- making. In J. Starkes, & A. Ericsson (Eds.), *Expert performance in sports: Advances in research on sport expertise* (pp. 192–218). Champaign, IL: Human Kinetics.

Tenenbaum, G. (2004). Decision making in sport. In C. Spielberger (Ed.), *Encyclopaedia of applied psychology, Vol. 1* (pp. 575–584). San Diego, CA: Elsevier.

Tenenbaum, G., Tehan, G., Stewart, G., & Christensen, S. (1999). Recalling a floor routine: the effects of skill and age on memory for order. *Applied Cognitive Psychology, 13*(2), 101–123.

Zoudji, B., & Thon, B. (2003). Expertise and implicit memory: differential repetition priming effects on decision-making in experienced and non-experienced soccer players. *International Journal of Sport Psychology, 34*(3), 189–207.