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Sherlock Holmes – an expert's view of expertise

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In recent years, there has been an intense research effort to understand the cognitive processes and structures underlying expert behaviour. Work in different fields, including scientific domains, sports, games and mnemonics, has shown that there are vast differences in perceptual abilities between experts and novices, and that these differences may underpin other cognitive differences in learning, memory and problem solving. In this article, we evaluate the progress made in the last years through the eyes of an outstanding, albeit fictional, expert: Sherlock Holmes. We first use the Sherlock Holmes character to illustrate expert processes as described by current research and theories. In particular, the role of perception, as well as the nature and influence of expert knowledge, are all present in the description of Conan Doyle's hero. In the second part of the article, we discuss a number of issues that current research on expertise has barely addressed. These gaps include, for example, several forms of reasoning, the influence of emotions on cognition, and the effect of age on experts' knowledge and cognitive processes. Thus, although nearly 120-year-old, Conan Doyle's books show remarkable illustrations of expert behaviour, including the coverage of themes that have mostly been overlooked by current research.

For over a century, numerous studies in psychology have aimed at understanding what differentiates experts from novices in a given domain. If the mental functioning of experts is not that of novices, what are the differences? This question has been addressed in many domains, such as chess (e.g. Binet, 1894; Chase & Simon, 1973; de Groot, 1946; Gobet, 1997; see Gobet, 1998b, for a review), mental calculation (e.g. Binet, 1894; Staszewski, 1988) and medical expertise (Myles-Worley, Johnston, & Simons, 1988; Norman, Brooks, & Allen, 1989; Rikers, Schmidt, & Boshuizen, 2002; Schmidt & Boshuizen, 1993).

From a methodological point of view, most of these studies have compared a sample of experts with a sample of novices in a series of tasks more or less related to the domain

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of interest. More rarely, some studies have examined a single expert, whose mental functioning is studied at length in experimental situations and/or in natural settings (e.g. Chaffin & Imreh, 2002; Ericsson, Delaney, Weaver, & Mahadevan, 2004; Gobet & Simon, 1996b). Although in the tradition of single-subject studies, our objective here is somewhat different. We do aim to observe a unique expert in a given domain, but this expert is *a literary figure*: Sherlock Holmes.

From 1887 to 1927, Conan Doyle wrote four novels and 56 short stories describing an expert in criminology, Sherlock Holmes, in several of his enquiries. Although there is a long literary tradition recounting the adventures of experts in criminology – policemen, detectives and others – Conan Doyle sets himself apart in his works not only by his deep-rooted interest in the scientific knowledge of the time (e.g. Snyder, 2004), but also by his declared intention to describe Sherlock Holmes' mental functioning through his discussions with Dr Watson. Since their first encounter in *A Study in Scarlet*, Watson closely follows the investigations carried out by Holmes, who attempts to explain to his good friend the secrets of his art from a cognitive point of view. Our aim in this article is twofold. Firstly, we want to show that Sherlock Holmes' mental functioning is a good reflection of our current knowledge of experts' thinking. Secondly, we identify several aspects of Sherlock Holmes' mental functioning that *are not addressed* in current research into cognitive expertise. We do not mean to provide a scientific analysis of Sherlock Holmes' mental processes that can shed new light on the field of expertise; rather, we use this fictional character as an illustration motivating reflection on the scientific study of expertise. Thus, we beg the reader not to take Sherlock Holmes too seriously as a scientific model of expertise, but to enjoy and reflect on the sometimes surprising twists that his adventures give to cognitive processes.

Sherlock Holmes 'decrypted' through our current knowledge of cognitive expertise

In cognitive psychology, modern works find their origin in de Groot's (1946) book on chess expertise. This book, which relies on the analysis of verbal protocols and experimental tasks, highlights two phenomena that constitute the foundation of current research into cognitive expertise. According to the first phenomenon, the study of expertise cannot be separated from the study of perception. Because experts' knowledge is different to novices', and because visual perception consists in a large part in evoking knowledge in order to structure perceived scenes (e.g. Henderson & Hollingworth, 1999), experts differ from novices as soon as a scene is perceived (Chase & Simon, 1973; Laurent, Ward, Williams, & Ripoll, 2006; Reingold, Charness, Pomplun, & Stampe, 2001; Reingold, Charness, Schultetus, & Stampe, 2001). Experts literally 'see' situations taken from their domain of expertise differently to novices. According to de Groot (1946), this perceptual advantage is one of the keys to experts' superior performance. A substantial part of recent research into expertise thus endeavours to understand the mechanisms underpinning expert perception (e.g. de Groot & Gobet, 1996; Reingold, Charness, Pomplun *et al.*, 2001; Reingold, Charness, Schultetus *et al.*, 2001). This research shows that experts and novices differ in the way they fixate domain-specific scenes or objects (Charness, Reingold, Pomplun, & Stampe, 2001; de Groot & Gobet, 1996; Reingold, Charness, Pomplun *et al.*, 2001), that experts perceive the relational elements of a scene in parallel while novices perceive them serially (Reingold, Charness, Schultetus *et al.*, 2001) and that experts' visual span is larger (Reingold, Charness, Pomplun *et al.*, 2001).

This characteristic of expertise is conspicuous with Sherlock Holmes who, even though he is not aware of it, 'sees' the objects and scenes he is confronted with differently to the way Watson sees them. In line with de Groot's concept of *dynamic* perception, Sherlock Holmes' perception includes automatic implicit inferences, and the boundary with explicit inferences is often blurred.

> 'I can see nothing', said I, handing it back to my friend.
>
> 'On the contrary, Watson, you can see everything. You fail, however, to reason from what you see. You are too timid in drawing your inferences'.
>
> 'Then, pray tell me what it is that you can infer from this hat?'
>
> He picked it up and gazed at it in the peculiar introspective fashion which was characteristic of him. 'It is perhaps less suggestive than it might have been', he remarked, 'and yet there are a few inferences which are very distinct, and a few others which represent at least a strong balance of probability. That the man was highly intellectual is of course obvious upon the face of it, and also that he was fairly well-to-do within the last three years, although he has now fallen upon evil days. He had foresight, but has less now than formerly, pointing to a moral retrogression, which, when taken with the decline of his fortunes, seems to indicate some evil influence, probably drink, at work upon him. This may account also for the obvious fact that his wife has ceased to love him'.
>
> 'My dear Holmes!'
>
> 'He has, however, retained some degree of self-respect', he continued, disregarding my remonstrance. 'He is a man who leads a sedentary life, goes out little, is out of training entirely, is middle-aged, has grizzled hair which he has had cut within the last few days, and which he anoints with lime-cream. These are the more patent facts which are to be deduced from his hat. Also, by the way, that it is extremely improbable that he has gas laid on in his house'. (Conan Doyle, 1892, p. 246, *The Adventure of the Blue Carbuncle*[1])

Experts' perception is different to novices', in the sense that perceiving consists in mobilizing knowledge for structuring perceived scenes. Now, the second phenomenon identified by de Groot (1946) is that experts set themselves apart from novices by their knowledge and long-term memory (LTM) organization. Thus, chess experts, for example, do not have larger domain-general memory (Chase & Simon, 1973) or computational capacity (de Groot, 1965; Gobet, 1998a; but see Holding, 1985, 1989) than novices. Their superiority comes from the nature and organization of their knowledge. To understand cognitive expertise is to understand how knowledge gets acquired and reorganized in memory as expertise develops. Most of the research into cognitive expertise thus aims to study and model expert memory, specifying the nature and the acquisition mechanisms of knowledge (e.g. Gobet, 1998b). Even though Sherlock Holmes has a rather naive conception of memory, one can find – pushed to its extreme given the way Holmes functions – the importance of knowledge and its organization in memory in Doyle's books.

> His ignorance was as remarkable as his knowledge. Of contemporary literature, philosophy and politics he appeared to know next to nothing. [. . .] My surprise reached a climax, however, when I found incidentally that he was ignorant of the Copernican Theory and of

[1] *This quotation, as well as all the quotations from Conan Doyle in this article, is taken from 'The Penguin Complete Sherlock Holmes', Penguin Books, 1981. The page numbers thus refer to this edition.*

> the composition of the Solar System. That any civilized human being in this nineteenth century should not be aware that the earth travelled round the sun appeared to be to me such an extraordinary fact that I could hardly realize it.
>
> 'You appear to be astonished', he said, smiling at my expression of surprise. 'Now that I do know it I shall do my best to forget it'.
>
> 'To forget it!'
>
> 'You see', he explained, 'I consider that a man's brain originally is like a little empty attic, and you have to stock it with such furniture as you choose. A fool takes in all the lumber of every sort that he comes across, so that the knowledge which might be useful to him gets crowded out, or at best is jumbled up with a lot of other things so that he has a difficulty in laying his hands upon it. Now the skilful workman is very careful indeed as to what he takes into his brain-attic. He will have nothing but the tools which may help him in doing his work, but of these he has a large assortment, and all in the most perfect order. It is a mistake to think that that little room has elastic walls and can distend to any extent. Depend upon it there comes a time when for every addition of knowledge you forget something that you knew before. It is of the highest importance, therefore, not to have useless facts elbowing out the useful ones'.
>
> 'But the Solar System!' I protested.
>
> 'What the deuce is it to me?' he interrupted impatiently; 'you say that we go round the sun. If we went round the moon it would not make a pennyworth of difference to me or to my work'. (Conan Doyle, 1887, p. 21, *A Study in Scarlet*)

This passage also points to an idiosyncratic characteristic of many experts: their extreme specialization which sometimes leads to a rather one-sided type of knowledge (de Groot, 1965). This ignorance naturally follows from the substantial number of hours that experts must devote to their domain to achieve top levels of performance (Ericsson, Krampe, & Tesch-Römer, 1993). However, this may be an oversimplification in the case of Sherlock Holmes who, in spite of the crass ignorance he sometimes displays as illustrated by the quotation above, possesses a rather wide knowledge in a variety of domains: among other things, he is expert in chemistry and biology, and plays the violin. In spite of its lack of sophistication on the functioning of memory, the passage quoted above also highlights a problem well known to mnemonists – the necessity of forgetting. Indeed, the inability to do just that incapacitated the life of the mnemonist studied by Luria (1968).

While it is not totally established, as argued by Sherlock Holmes, that becoming an expert consists in storing only situations taken from one's domain of expertise (see Gobet, Campitelli, & Waters, 2002, for a discussion of the links between chess expertise and general knowledge), becoming an expert depends without any doubts on constructing a large and well-organized knowledge base. Thus, one of the key questions concerns the nature of expert knowledge. Expert knowledge appears to be organized as knowledge networks with differing levels of abstraction. Whatever the domain of expertise under scrutiny, empirical evidence highlights the fact that specific and more abstract knowledge coexist in memory.

First of all, it seems that expert memory contains knowledge with a low level of abstraction, which is known under different names such as 'chunks', 'scripts' or 'cases' (e.g. Chase & Simon, 1973; Hammond, 1990; Kolodner, 1993). It appears that knowledge also contains more abstract and schematic elements, which can be adapted to a larger class of situations (Chi, Feltovich, & Glaser, 1981; Cooke, Atlas, Lane, & Berger, 1993; Gobet & Simon, 1996a; McGregor & Howes, 2002). The coexistence of these two types of knowledge is obvious in Sherlock Holmes' mental functioning.

On one hand, he constantly attempts to link the investigation in progress to the situations stored in his episodic memory. Starting from the principle that '*there is a strong family resemblance about misdeeds, and if you have all the detail of a thousand at your finger ends, it is odd if you can't unravel the thousand and first*', Sherlock Homes often recalls past inquiries to adapt them to the case at hand (e.g. '*It reminds me of the circumstances attendant on the death of Van Jansen, in Utrecht, in the year '34*'. Conan Doyle, 1887, p. 29, *A Study in Scarlet*). But equally, he has a rich répertoire of more general knowledge that can be used in a variety of occasions. Thus, in the following example, taken from *The Adventure of the Priory School* in 1904 (p. 547), Sherlock Holmes makes it clear that his memory contains knowledge at a higher level of abstraction and generality than the specific situations that he has met:

> 'This track, as you perceive, was made by a rider who was going from the direction of the school'.
>
> 'Or towards it?'
>
> 'No, no, my dear Watson. The more deeply sunk impression is, of course, the hind wheel, upon which the weight rests. You perceive several places where it has passed across and obliterated the more shallow mark of the front one. It was undoubtedly heading away from the school'.

In this example, it is likely that if the knowledge Holmes is using originally was constituted of specific instances, it was later elaborated so that numerous specific elements have been deleted and replaced by 'variables'. To account for this type of knowledge, Gobet and Simon (1996a, 2000) proposed that expert memory consists, among others things, of 'templates'. These LTM knowledge structures combine specific and variable elements. Computer simulations with chess show how templates are acquired and how they are used in recall tasks.

Due to the presence of variables, these structures allow material (elements of a scene, objects and verbal information) to be encoded very rapidly in LTM, assuming of course that the material is taken from the domain of expertise. Thus, with the help of these structures, a waiter can rapidly memorize a large number of orders beyond the capacity of his working memory (e.g. Ericsson & Polson, 1988), and chess players can rapidly memorize a large number of pieces belonging to several boards (e.g. Gobet & Simon, 1996a). When Sherlock Holmes arrives to the scene of a crime, he appears to be able to store rapidly and automatically the relevant elements. '*It was one of the peculiarities of his proud, self-contained nature that though he docketed any fresh information very quietly and accurately in his brain, he seldom made any acknowledgement to the giver*'. (Conan Doyle, 1924, p. 1035, *The Adventure of the Sussex Vampire*). This notion of variables to which values can be set is opposed by Ericsson and Kintsch (1995, 2000), who propose that the mechanisms inherent to long-term working memory are used instead (see Ericsson & Kintsch, 2000, Gobet, 2000a, b, for a discussion of the similarities and differences between long-term working memory theory and template theory).

A second characteristic of schematic knowledge in expert memory is that it contains semantic information on the likely continuations of the current situation. Thus, when a chess position is encoded, templates automatically elicit possible moves or sequences of moves from this position (Ferrari, Didierjean, & Marmèche, 2006; Gobet & Simon, 1996a). Similarly, a basketball expert automatically activates sequences of play (Didierjean & Marmèche, 2005). As a consequence, when an event occurs that differs from what was predicted by the activated knowledge structure, this provokes an expectation failure (Schank, 1982; Kolodner, 1993), which draws attention.

This characteristic appears several times in Sherlock Holmes' mental functioning. For example, in *Silver Blaze* (p. 347), in 1892:

> 'Is there any point to which you would wish to draw my attention?'
>
> 'To the curious incident of the dog in the night-time'.
>
> 'The dog did nothing in the night-time'.
>
> 'That was the curious incident', remarked Sherlock Holmes.

The presence of knowledge enables Sherlock Holmes to carry out a causal chaining of events, and even enables him to perform genuine proofs by contradiction, as is shown in the following situation published in *The Adventure of the Priory School* (p. 549–550) in 1904:

> 'First of all I wish to impress upon you that the boy certainly left of his own free will. He got down from his window and he went off, either alone or with someone. That is sure'.
>
> I assented.
>
> 'Well, now, let us turn to this unfortunate German master. The boy was fully dressed when he fled. Therefore, he foresaw what he would do. But the German went without his socks. He certainly acted on very short notice'.
>
> 'Undoubtedly'.
>
> 'Why did he go? Because, from his bedroom window, he saw the flight of the boy; because he wished to overtake him and bring him back. He seized his bicycle, pursued the lad, and in pursuing him met his death'.
>
> 'So it would seem'.
>
> 'Now I come to the critical part of my argument. The natural action of a man in pursuing a little boy would be to run after him. He would know that he could overtake him. But the German does not do so. He turns to his bicycle. I am told that he was an excellent cyclist. He would not do this if he did not see that the boy had some swift means of escape'.
>
> 'The other bicycle'.
>
> 'Let us continue our reconstruction. He meets his death five miles from the school – not by a bullet, mark you, which even a lad might conceivably discharge, but by a savage blow dealt by a vigorous arm. The lad, then, had a companion in his flight. And the flight was a swift one, since it took five miles before an expert cyclist could overtake them. Yet we survey the ground round the scene of the tragedy. What do we find? A few cattle tracks, nothing more. I took a wide sweep round, and there is no path within fifty yards. Another cyclist could have had nothing to do with the actual murder. Nor were there any human footmarks'.
>
> 'Holmes', I cried, 'this is impossible'.
>
> 'Admirable!' he said. 'A most illuminating remark. It IS impossible as I state it, and therefore I must in some respect have stated it wrong. Yet you saw for yourself. Can you suggest any fallacy?'
>
> 'He could not have fractured his skull in a fall?'
>
> 'In a morass, Watson?'
>
> 'I am at my wit's end'.
>
> 'Tut, tut; we have solved some worse problems'.

Thus, Sherlock Holmes presents all mental characteristics described by research into cognitive expertise. He perceives the scenes and objects of his domain of expertise differently to novices. To do this, he uses knowledge that novices do not have. In particular, he appears to have specific episodic knowledge, acquired through past experiences, and also knowledge of a more schematic nature. The latter enables him to very rapidly encode the elements of a problem and to orient him to likely outcomes. However, Sherlock Holmes also presents a number of characteristics that have not or that have rarely been studied in research into cognitive expertise, although they may have been studied in other fields of psychology.

When Sherlock Holmes opens up new research directions

One of the first questions raised by the study of Sherlock Holmes relates to the origin of his expertise. What are the links between expertise and intelligence? Is Holmes what he is only through hard work, or does he have intrinsic qualities that would make somebody else with the same knowledge less expert? On this question, the literature on cognitive expertise contains experimental results that are rather contrasting, and sometimes even contradictory. To begin with, it is clear that, in most domains, becoming an expert requires a large number of hours of practice. Nobody becomes a chess or violin expert in 1 hour; rather, to-be experts must invest a substantial amount of time in deliberate work. This characteristic of cognitive expertise has been theorized by Ericsson *et al.* (1993) with the concept of 'deliberate practice' and seems to be one of the prerequisites of expertise in all domains (e.g. Hodges, Kerr, Starkes, Weir, & Nananidou, 2004; Howe, Davidson, & Sloboda, 1998; Van Gelder & Bisset, 2004). Sherlock Holmes does not depart from this rule, his expertise being the fruit of years of learning through reading and experimentation. His determination to learn is on a par with his expertise, and sufficiently unusual for Watson to be warned by one of his friends before meeting Sherlock Holmes for the first time in '*A study in Scarlet*' (1887, p. 17):

> 'Holmes is a little too scientific for my tastes – it approaches to cold-bloodedness. I could imagine his giving a friend a little pinch of the latest vegetable alkaloid, not out of malevolence, you understand, but simply out of a spirit of inquiry in order to have an accurate idea of the effects. To do him justice, I think that he would take it himself with the same readiness. He appears to have a passion for definite and exact knowledge'.
>
> 'Very right too'.
>
> 'Yes, but it may be pushed to excess. When it comes to beating the subjects in the dissecting-rooms with a stick, it is certainly taking rather a bizarre shape'.
>
> 'Beating the subjects!'
>
> 'Yes, to verify how far bruises may be produced after death. I saw him at it with my own eyes'.

Although few would deny the role of deliberate practice, or at least of practice, in the acquisition of expertise (however, see Sternberg, 1996), an important question is whether deliberate practice is the *only* determining factor in the acquisition of expertise, or whether prior aptitudes that may differ across individuals are necessary as

well. In the literature on expertise, most of the studies on this theme compare a group of experts in a given domain with a group of non-experts, using a large number of tasks measuring cognitive aptitudes. The results of these experiments offer a rather contradictory picture.

Some of these studies highlight the independence between personal aptitudes and expertise. For example, in music (e.g. Helmbold, Rammsayer, & Altenmuller, 2005) and chess (e.g. Unterrainer, Kaller, Hallsband, & Rahm, 2006; Waters, Gobet, & Leyden, 2002), it has been found that experts and non-experts obtained equivalent performance on intelligence tasks. By contrast, other studies that also compared chess or music experts with non-experts in several measures of cognitive ability found significant differences favouring the experts, which support the role of innate abilities (e.g. Cooley, 1961; Frydman & Lynn, 1992; Horgan & Morgan, 1990).

Teasing apart the roles played by talent and practice in expertise is particularly complex due to the fact that the two factors are not independent (Sternberg, 1996). For example, in a study contrasting children playing chess at different levels of expertise, Bilalić, McLeod, and Gobet (2007) show the extent to which expertise, practice and abilities are interrelated. They found that, while there was an effect of intelligence at the beginning of learning, children with the highest IQ (as measured by the WISC) being the best at chess, this effect disappeared thereafter. With an elite subsample of children having played chess for longer (5.5 vs. 3.5 years), the best chess-playing children did not have a higher IQ than the weaker children. However, their results also show that the most intelligent children devote *the least time* to practice. Yet in their study, practice was the explanatory factor that correlated most with success in chess. This study is a good example of the assertion that, while the respective roles of practice and intelligence are an important domain of research, studying this issue will be highly difficult as the various factors are not independent. This difficulty in separating both factors can also be observed with Sherlock Holmes. We mentioned earlier that he had devoted a considerable amount of time to practice and study in order to acquire his expertise. Yet in '*The adventure of the Gloria Scott*' in 1893 he recounts how his realization of his aptitude for deduction explains why he, rather than somebody else, was oriented towards an intense activity of 'deliberate practice'.

Thus, the question remains as to the presence of natural talents in Sherlock Holmes. Although it is not possible to give an IQ test to Sherlock Holmes, everything suggests that he had an exceptional intelligence. In his book on Sherlock Holmes' intelligence, Radford (1999) proposes three different methods for estimating Sherlock Holmes' IQ from Conan Doyle's stories. The three methods converge and lead Radford to the identification of cues that strongly suggest an extremely high level of intelligence in this literary character. Where do these abilities come from? Because his brother, Mycroft, appears to have abilities at least equal to his, Sherlock Holmes thinks that, in spite of his hard work, his skills are mainly hereditary, as he explains to Watson in '*The Greek interpreter*' (1893, p. 435):

> 'In your own case', said I, 'from all that you have told me, it seems obvious that your faculty of observation and your peculiar facility for deduction are due to your own systematic training'.
>
> 'To some extent', he answered, thoughtfully. 'My ancestors were country squires, who appear to have led much the same life as is natural to their class. But, none the less, my turn

> that way is in my veins, and may have come with my grandmother, who was the sister of Vernet, the French artist. Art in the blood is liable to take the strangest forms'.
>
> 'But how do you know that it is hereditary?'
>
> 'Because my brother Mycroft possesses it in a larger degree than I do'.

However, one should be more cautious than Sherlock Holmes with respect to the conclusions that can be drawn from the existence of Mycroft. Indeed, the history of psychology shows that the utmost caution would have been required even if Holmes had had a monozygotic twin raised in a different social environment. While it is unfortunately impossible in the case of Sherlock Holmes to tease apart what comes from innate talent and what comes from acquired knowledge, this is clearly an issue that should be explored in the future with other experts and in other fields of expertise.

Although a fair amount of research has studied the link between expertise and performance in problem solving (Barfield, 1986; de Groot, 1946; Gobet & Simon, 1996b; Gobet, 1997; Larkin, McDermott, Simon, & Simon, 1980; Saariluoma, 1990), a second aspect of Sherlock Holmes' functioning that has not been studied in detail to this day is experts' reasoning. Perhaps because works on expertise have often used memory tasks, expert reasoning is certainly the least understood component of expert behaviour. With the exception of research into clinical reasoning in medicine (Patel & Groen, 1986) and Cleveland's (1907) explicit use of the term 'reasoning' in his chess study, when this question is addressed, the mechanisms under scrutiny typically relate to the use of inductive reasoning in order to extract generality (Gobet & Simon, 1996a) or to the role of goal structures in problem solving (Gobet, 1997; Saariluoma, 1990, 1992a). By contrast, Sherlock Holmes, very often, uses abductive reasoning. With this form of reasoning, one starts from observed data, and then derives the most likely explanation or hypothesis. This explanation makes it possible to deduce the data by implication (e.g. Hanson, 1958). Holmes provides an explanation for this method of thought to Watson in *A Study in Scarlet* (p. 83–84) in 1887:

> 'In solving a problem of this sort, the grand thing is to be able to reason backward. That is a very useful accomplishment, and a very easy one, but people do not practice it much. In the everyday affairs of life it is more useful to reason forward, and so the other comes to be neglected. There are fifty who can reason synthetically for one who can reason analytically'. 'I confess', said I, 'that I do not quite follow you'.
>
> 'I hardly expected that you would. Let me see if I can make it clearer. Most people, if you describe a train of events to them, will tell you what the result would be. They can put those events together in their minds, and argue from them that something will come to pass. There are few people, however, who, if you told them a result, would be able to evolve from their own inner consciousness what the steps were which led up to that result. This power is what I mean when I talk of reasoning backward, or analytically'.

This kind of reasoning is rare in research into cognitive expertise (but see Van Gog, Paas, & Van Merrienboer, 2005, for research into electrical circuit troubleshooting), even though it probably occurs in many domains (e.g. an expert in car repair should be able to derive hypotheses on the likely causes of a breakdown, and an airline crash investigator should be able to infer the likely causes of an accident). Even in domains where decisions must be made very rapidly and where this type of reasoning is not present *during* the action (e.g. during a basketball match), the phases of knowledge acquisition, which constitute an important part of the development of expertise, often

focus on the analysis of situations where the understanding of the goals underpinning the situations under analysis play a predominant role. Thus, a good understanding of the mental functioning of experts requires a good knowledge of the reasoning mechanisms that they are using and that occur at different moments in the development of expertise. Similarly, there is little work in expertise research on the analysis of the role and nature of the metacognitive mechanisms engaged in cognitive expertise (however, see Horgan, 1992), even though these mechanisms play an important role. Thus, Sherlock Holmes often deploys such mechanisms, as illustrated by this comment by Watson in *The Adventure of the Creeping Man* (p. 1071) in 1923:

> I was a whetstone for his mind. I stimulated him. He liked to think aloud in my presence. His remarks could hardly be said to be made to me – many of them would have been as appropriately addressed to his bedstead – but none the less, having formed the habit, it had become in some way helpful that I should register and interject. If I irritated him by a certain methodical slowness in my mentality, that irritation served only to make his own flame-like intuitions and impressions flash up the more vividly and swiftly. Such was my humble role in our alliance.

Although the role of explanations and self-explanations is well known in learning research (e.g. Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, De Leeuw, Chiu, & La Vancher, 1994; Van Lehn, 1998), there is little research about this type of mechanism in expert functioning, and further studies would be welcome.

A third aspect where more work is needed is the role of 'atypical' situations. Sherlock Homes repeatedly emphasizes the interest of situations that are out of the ordinary for the efficient use of reasoning. Thus, in *A Study in Scarlet* (Conan Doyle, 1887, p. 83), he mentions this point:

> 'I would not have missed the investigation for anything. There has been no better case within my recollection. Simple as it was, there were several most instructive points about it'.
>
> 'Simple!' I ejaculated.
>
> 'Well, really, it can hardly be described as otherwise', said Sherlock Holmes, smiling at my surprise. 'The proof of its intrinsic simplicity is, that without any help save a few very ordinary deductions I was able to lay my hand upon the criminal within three days'.
>
> 'That is true', said I.
>
> 'I have already explained to you that what is out of the common is usually a guide rather than a hindrance'.

In most domains of expertise, atypical situations are of particular interest. Especially in competitive domains, experts should sometimes be unpredictable. Thus, de Groot (1965, p. 192) in his book on chess expertise notes that masters should be able to play unexpected moves and plans: '*Noblesse oblige*: because of the high expectation certain methods of play do not come into consideration'. In the field of face recognition, where everybody is expert to some extent, atypical elements are crucial (Light, Kayra-Stuart, & Hollander, 1979). Now, even though it seems rather clear that taking into account atypical elements is an important dimension of expertise, there is relatively little research on this point, except in some work into medical expertise (e.g. Myles-Worsley & Johnston, 1988) and chess (Goldin, 1978). To understand how prototypical and atypical situations are stored and coexist in experts' memories is one of the important issues for further research.

Together with atypical situations, situations to avoid should be learned by experts, as these lead to impasses. The role of errors, be they one's own errors or those of somebody else, is strikingly illustrated by Sherlock Holmes when he teases Watson for his reasoning mistakes:

> 'Really, Watson, you excel yourself', said Holmes, pushing back his chair and lighting a cigarette. 'I am bound to say that in all the accounts which you have been so good as to give of my own small achievements you have habitually underrated your own abilities. It may be that you are not yourself luminous, but you are a conductor of light. Some people without possessing genius have a remarkable power of stimulating it. I confess, my dear fellow, that I am very much in your debt'.
>
> He had never said as much before, and I must admit that his words gave me keen pleasure, for I had often been piqued by his indifference to my admiration and to the attempts which I had made to give publicity to his methods. I was proud, too, to think that I had so far mastered his system as to apply it in a way which earned his approval. He now took the stick from my hands and examined it for a few minutes with his naked eyes. Then, with an expression of interest, he laid down his cigarette, and, carrying the cane to the window, he looked over it again with a convex lens.
>
> 'Interesting, though elementary', said he, as he returned to his favourite corner of the settee. 'There are certainly one or two indications upon the stick. It gives us the basis for several deductions'.
>
> 'Has anything escaped me?' I asked, with some self-importance. 'I trust that there is nothing of consequence which I have overlooked?'
>
> 'I am afraid, my dear Watson, that most of your conclusions were erroneous. When I said that you stimulated me I meant, to be frank, that in noting your fallacies I was occasionally guided towards the truth'. (Conan Doyle, 1901, pp. 669–670, *The Hound of the Baskervilles*)

Although the role of errors on memory retrieval has been shown in some domains (e.g. Didierjean & Nogry, 2004; Gick & McGarry, 1992; Patalano & Seifert, 1994), there remains much to understand about the role these phenomena play in expert memory.

A fourth aspect awaiting further developments concerns the role of emotions in expertise. In many domains, the control of emotions is part of expertise, but, to this day, this dimension has been relatively under-researched. Chaffin and Imreh (2002) describe how, when learning a piano concerto, an expert pianist associated passages of the piece to particular emotions. In chess, de Groot (1965, p. 195) observes that

> If there are more moves that correspond to the direction (board goal), often while scanning the possibilities the subject 'intuitively' choose a tentative favorite. Rarely does completely pure, comparative examining of different considerable moves or plans occur without a trace of emotional preference for one of them.

Sherlock Holmes also mentions the influence that emotions can have on his art: '*But love is an emotional thing, and whatever is emotional is opposed to that true cold reason which I place above all things. I should never marry myself, lest I bias my judgment*'. (Conan Doyle, 1890, p. 157, *The Sign of Four*)

Clearly, more studies should be carried out to better integrate the role of emotions to our understanding of expertise.

Finally, a dimension that should be pursued vigorously concerns the effects of ageing on expert cognition (e.g. Charness, 1981a, b, 1983, Charness, Tuffiash, Krampe,

Reingold, & Vasyukova, 2005; Taylor, O'Hara, Mumenthaler, Rosen, & Yesavage, 2005). How do the various characteristics of cognitive expertise evolve with age? Thus, while Sherlock Holmes depicted himself as showing little interest to anything that did not relate to his art: '*Appreciation of nature found no place among his many gifts, and his only change was when he turned his mind from the evildoer of the town to track down his brother of the country*' (Conan Doyle, 1893, p. 423, *The Resident Patient*), he seems to evolve with age:

> 'But you have retired, Holmes. We heard of you as living the life of a hermit among your bees and your books in a small farm upon the South Downs'.
>
> 'Exactly, Watson. Here is the fruit of my leisured ease, the magnum opus of my latter years!' He picked up the volume from the table and read out the whole title, Practical Handbook of Bee Culture, with Some Observations upon the Segregation of the Queen. 'Alone I did it. Behold the fruit of pensive nights and laborious days when I watched the little working gangs as once I watched the criminal world of London'. (Conan Doyle, 1917, p. 978, *His Last Bow*)

While this question of ageing is interesting in itself, it is also important for understanding the nature of the mechanisms underpinning expertise and cognition in general. With age, some mechanisms such as working memory and processing speed deteriorate (e.g. Craik & Salthouse, 2000; Parkin & Walter, 1991; Salthouse, 1996). By contrast, others remain stable, such as implicit memory (e.g. Hultsch, Masson, & Small, 1991) or implicit learning (e.g. Salthouse, McGuthry, & Hambrick, 1999). By studying the effects of age on expertise, one is likely to better understand the weight of these factors in different domains of expertise (e.g. Mireles & Charness, 2002).

The extract from Sherlock Holmes' adventures that we have presented also illustrate another important question concerning expertise: to what extent is cognitive expertise in one domain transferable to other domains? Some studies show that experts' performance can be inferior to that of intermediates in some tasks (e.g. Schmidt & Boshuizen, 1993; Voss, Vesonder, & Spilich, 1980; Wiley, 1998). However, in most of these studies, the chosen tasks are precisely constructed to have a link with the domain of expertise, but in which knowledge underpinning expertise leads to inferior performance. Take for example, the 'intermediate effect' found in medical expertise, where medicine students, although they provide weaker diagnoses than expert physicians, recall more information from the clinical case they had to diagnose (Schmidt & Boshuizen, 1993). This type of effects probably relates to the generalization capacity typical of expert memory, as discussed in the first part of our article. But the development of more abstract knowledge is often synonymous of transfer in the literature. An important topic for further research is to investigate to which extent certain types of cognitive expertise are transferable to other domains.

Conclusion

When he explains his art to Watson, Sherlock Holmes unwittingly offers a good overview of our current knowledge of cognitive expertise, but he also raises a number of issues that certainly remain to be studied in the future. However, Sherlock Holmes' declared will to verbalize what relates to his art also brings about two important points. Firstly, the role of language in expertise. It is possible that providing explanations to Watson *contributes* to Sherlock Holmes' expertise by forcing him to develop a verbal expertise. Some studies show that, in domains such as face expertise (Schooler &

Engstler-Schooler, 1990) or wine expertise (Melcher & Schooler, 1996), verbalizations on an example actually deteriorate its memory trace if perceptual expertise is not accompanied by a verbal expertise of the domain. Thus, wine lovers who do not have the oenological vocabulary necessary for describing wine memorized wines they had described less well than wines about which they did not provide verbalizations (Melcher & Schooler, 1996). In contrast to these studies showing the importance of verbal knowledge, other studies in chess show that verbal interfering tasks do not affect players' performance much (Robbins *et al.*, 1995; Saariluoma, 1992b). On this basis, most models of cognitive expertise propose a memory organization essentially based on perceptual knowledge. An important goal for future research is to understand the link between perceptual and verbal knowledge.

Finally, do Sherlock Holmes' verbalizations reflect all the aspects of his art? Nothing is less sure. While there are numerous studies in psychology dealing with implicit memory, only few of them deal with this type of memory with experts (see, for example, Beilock, Carr, MacMahon, & Starkes, 2002). However, it is likely that knowledge of an implicit, non-verbalizable kind lies at the basis of cognitive expertise – what is sometimes called 'intuition'. Thus, de Groot (1965, p. 306) in his seminal work on chess expertise observed that '*A master does not search for a good move, he sees it*'. This aspect of expertise, likely to influence Sherlock Holmes as much as any less virtual expert, still remains to be explored.

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