Chapter 9

The paradox of human expertise: why experts get it wrong

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Summary

Expertise is correctly, but one-sidedly, associated with special abilities and enhanced performance. The other side of expertise, however, is surreptitiously hidden. Along with expertise, performance may also be degraded, culminating in a lack of flexibility and error. Expertise is demystified by explaining the brain functions and cognitive architecture involved in being an expert. These information processing mechanisms, the very making of expertise, entail computational trade-offs that sometimes result in paradoxical functional degradation. For example, being an expert entails using schemas, selective attention, chunking information, automaticity and more reliance on top-down information, all of which allows experts to perform quickly and efficiently; however, these very mechanisms restrict flexibility and control, may cause the experts to miss and ignore important information, introduce tunnel vision and bias and can cause other effects that degrade performance. Such phenomena are apparent in a wide range of expert domains, from medical professionals and forensic examiners, to military fighter pilots and financial traders.

Expertise is highly sought after – only those with special abilities, after years of training and experience, can achieve those exceptional brain powers that make them experts. Indeed, being an expert is most often prestigious, well-paid, respected and in high demand. However, examining expertise in depth raises some interesting and complex questions. In this chapter, I will take apart and reject the myth that experts merely have superior performance per se. I will not only show that experts are not exclusively superior or infallible, but that they are in fact sometimes prone to specific types of degradations and errors.

Examining expertise from a cognitive neuroscientific perspective offers an opportunity to understand that expertise is not about being faster and more efficient, but rather that experts go about things differently. This leads to high performance in most cases, but not always. Paradoxically, the very underpinning of expertise can entail degradation in performance as well, such as tunnel vision and biases. These are inherent computational and cognitive trade-offs resulting from the brain functions of experts. These trade-offs mean that as you enhance performance in some aspects, you may decrease it in others. For example, as experts modify their mental representations, they form very efficient brain

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mechanisms, but these very mechanisms are inherently automatic and rigid, causing vulnerabilities that may result in degradation and error (Sternberg, 2002; Stanovich, 2009).

To understand these mechanisms and their trade-offs, I start off with a discussion about the world of experts and expertise. Then, I explore the brains and cognitive mechanisms of experts, examining specific mental representations and architectures. Their paradoxical nature will be highlighted by computational trade-offs, and their functional degradation will be illustrated through expertise in real-world domains.

Recognizing and labelling an individual as an expert is to a large extent a social construct, often based on education, certification and social acceptance. These are not considered here, because the focus is on the actual expertise *de facto*. In other words, what are the brain and cognitive makings of an expert, rather than the external social issues involved (there may well be experts who are not socially recognized as experts, and – conversely – there may be recognized ‘experts’ who in fact do not possess sufficient – or any – expertise). Hence, I examine expertise from its *actual* brain and cognitive underpinning, rather than addressing social notions of expertise. I am interested in the ontology of what *actually* constitutes expertise, rather than the epistemological questions of how we recognize and know who an expert is.

Even within the brain and cognitive literature, sometimes the notion of expertise has been diluted and even dissolved by attributing it to everyone. For example, many researchers regard people as ‘experts’ in face recognition (e.g. Schwaninger *et al.*, 2003; Carey, 1992; Tanaka, 2001). Indeed, people have an excellent ability to recognize faces. However, since everyone possesses this ability[1] (effortlessly and without needing specialized training), it does not, in essence, constitute expertise in the way I conceptualize and address it.

Expertise is discussed and conceptualized in terms of expert performance, expertise in the sense of special abilities that only some people possess, in contrast to others who are not experts – the novices – who cannot perform to the levels of experts (e.g. Dror *et al.*, 1993; Wood, 1999). These abilities may entail different types of knowledge and performance characteristics associated with different expertise. For example, declarative vs. procedural knowledge (Squire, 1994; see ‘knowing that’ vs. ‘knowing how,’ Ryle, 1946, 1949). Declarative knowledge, *knowing that*, is more factually based and may be more related to academic and intellectual experts who understand certain things (but may not be able to ‘do’ anything with it), whereas procedural knowledge, *knowing how*, is more related to performing an act, where an expert knows how to do certain things (but may not understand much or anything about it). For instance, an expert physicist knows the laws of physics, but may not know how to ride a bicycle, drive a car or fly an airplane. In contrast, expert drivers and pilots will know how to drive and race a car, or fly an aircraft, but may have no knowledge of the physics underlying their expert performance. Indeed, trying to access declarative knowledge can even interfere with expert performance that relies on procedural knowledge, e.g. expert golfers (Flegal and Anderson, 2008).

The distinction between expertise being based on *knowing that* or on *knowing how* is directly related to the real-world domains of expertise. For example, in the medical domain some specialists may have expertise in diagnosis, knowing how to read, for instance, X-rays; being able to *know that* a ‘tumour is present’, whereas other experts,

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[1] Except patients with developmental or acquired prosopagnosia, who have specific impairments in recognizing faces.

such as surgeons, may specialize and have expertise in executing medical procedures, i.e. *know how* to remove the tumour. Some expert domains are clearly characterized more by one type of knowledge, e.g. music, sports and other performing experts are based on knowing how. Although experts may have both types of knowledge, often they need to rely on one type of knowledge rather than the other (e.g. in policing, see Dror, 2007). The type of expert knowledge that is most appropriate depends on the situational demands and on the cognitive mechanisms involved in operationalizing this knowledge; e.g. time constraints (e.g. Beilock *et al.*, 2004; Dror, 2007).

Experts often have special 'talent'; in other words, special and specific cognitive abilities needed to perform tasks associated with their expert domain. Astronauts have mental imagery abilities that are important for controlling a robotic arm during Space Shuttle and International Space Station missions (Menchaca-Brandan *et al.*, 2007). Cognitive ability to inhibit an ongoing action in response to a signal from the environment is important for expert baseball batting (Gray, 2009). Many specific cognitive abilities are important in the medical domain, and specifically in surgery (e.g. Tansley *et al.*, 2007). These examples of baseball batting and surgical competence relate to expertise that are characterized by knowing how, as they require, and extensively rely on, the ability to perform an action – executing a motor command.

If cognitive abilities are important for such expertise, then domains that are much more cognitively oriented, such as requiring visualization and pattern matching, are critically dependent on cognitive abilities. Take, for example, the reliance on spatial visualization in technical graphics and engineering design (Yue, 2007); the examination and comparison of impression and pattern evidence in forensic domains (Dror and Cole, 2010); the visualization of three-dimensional structures of molecules from two-dimensional representations in chemistry (Pribyl and Bodner, 1987); or the visualization of body parts and their spatial relations by clinical anatomists (Fernandez *et al.*, 2011) and verbal and visuospatial abilities of expert Scrabble players (Halpern and Wai, 2007).

Experts have abilities and capabilities that enable them to perform at much higher levels than non-experts, the novices.[2] To achieve such performance levels, experts need to have well-organized knowledge, use sophisticated and specific mental representations and cognitive processing, apply automatic sequences quickly and efficiently, be able to deal with large amounts of information, make sense of signals and patterns even when they are obscured by noise, deal with low quality and quantity of data, or with ambiguous information and many other challenging task demands and situations that otherwise paralyse the performance of novices (e.g. Patel *et al.*, 1999; Wood, 1999; Dror *et al.*, 1993). Such expert abilities and cognitive performance have been associated with specialized brains; for example, in musicians (Gaser and Schlaug, 2003), radiologists (Harley *et al.*, 2009), mathematicians (Aydin *et al.*, 2007), forensic examiners (Busey and Vanderkolk, 2005), taxi drivers (Maguire *et al.*, 2000) and even jugglers (Draganski *et al.*, 2004).

Experts have abilities and knowledge that has been acquired by repeated exposure to the tasks they need to perform. With time, they tune into and pick out the important and relevant information, learning how to detect and use it well while ignoring and filtering

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[2] I conceptualize expertise as a continuum with different levels of performance abilities rather than a dichotomy. Indeed, in some domains there is clear quantification of expert levels, such as chess (e.g. Elo, 2008). In other domains which are not so well-defined, it is more difficult to clearly quantify levels of expertise, but there is nevertheless a range of levels.

out everything else (e.g. Kundel and Nodine, 1983; Wood, 1999). Experts are driven by knowledge contained in specific mental representations and schemas which they have acquired by learning and experience (see Russell, 1910, for the distinction between knowledge by *description* vs. knowledge by *acquaintance*). Armed with these expert tools, they select and focus on the specific signals that are relevant, and perform quickly and efficiently even in environments that contain little data or noise (e.g. Gold *et al*., 1999; Lu and Dosher, 2004).

Training of experts can be improved and enhanced by helping them learn the important and critical signals. For example, expertise in aircraft identification requires knowledge of the distinguishing and distinctive features of each aircraft, and how to utilize them to identify aircraft in a whole spectrum of orientations. Initially identification is difficult, if not impossible. However, through repeated exposure to aircraft, experts learn the critical signals that characterize each aircraft, and use these for identification. Dror *et al.* (2008) enhanced the efficiency and effectiveness of acquiring this expertise by artificially *exaggerating the distinctive and unique features* of each aircraft during training. The enhanced training not only reduced the time needed to acquire this expertise, but it also produced more effective mental representations that improved performance later during testing (see Dror *et al*., 2008, for more details). With such knowledge, experts can deal with complex and difficult tasks with relative ease, seemingly performing instantaneously and effortlessly.

Experts' ability to perform with relative ease is surprising given the brain's limited capacity and resources to process information. However, this is exactly the point: experts deal with *cognitive load* by mental representations and cognitive processes that are computationally efficient. This enables them to perform at high levels in the face of constraints imposed by the brain. Certainly, one of the impediments on the performance of novices is the brain's limited capacity to process information. Experts overcome these constraints in a number of ways that allow them to perform well; however, these solutions also entail a cost – the associated degradation.

Experts often report that they 'see things differently'. Indeed, a cornerstone of expertise is that they modify how they represent information and the brain's neuronal mechanisms that process it. There are a few typical changes in *knowledge organization* with expertise, which affect mental representations and processing. The common denominator of such changes is that they re-package the information in ways that make it more efficient to perform certain tasks. An everyday example of how people do such cognitive 're-packaging' is when we 'chunk' information together. Chunking means that cognitive load is reduced by lumping things together in mental representations that fit the task demands. For instance, consider how people memorize and use phone numbers. They start off with singular digits, but as they gain experience and use a number, they often 'chunk' some of the digits together, re-packing the phone number (or area code) to a smaller number of units of information. Using different mental representations to reduce cognitive load and increase efficiency is a general cognitive and brain mechanism that is used when the available resources are stretched; for example, older people may adopt more computationally efficient mental representations (Dror *et al*., 2005).

With expertise, mental representations are formed to fit the specific task demands while controlling for cognitive load. For example, Czerwinski *et al*. (1992) suggest 'perceptual unitization', whereby conjunctions of features are chunked together so they are perceived as a single entity. Unitization creates new entities and neural processing that causes components that were once perceived separately to become fused together (Schyns and Rodet, 1997). Such new brain organization plays an important role in expertise (Goldstone, 2000; Shiffrin and Lightfoot, 1997). However, the price of making such expertise-based unitizations is that the components are less available, if not inaccessible altogether (Fusi *et al.*, 2005; Kepecs *et al.*, 2002).

The re-occurrence of typical configuration arrangements in expert domains results in lumping them and jointly putting them together within a mental representation. Expert chess players are a good illustration of this mechanism, exemplifying its advantages as well as its functional degradation. Expert chess players do not represent board positions by constituting individual pieces on the board; rather, they often chunk them together into meaningful patterns. Indeed, expert chess players are much better than novices in encoding and remembering board positions. However, the more efficient representations are constructed to fit certain situations and address specific task demands and experiences. That means that these mechanisms of representing information are effective and efficient, but only under certain conditions. The enhanced functional performance is limited; the chess experts are indeed better than novices in encoding and remembering board positions, but this is limited only to realistic board positions. Experts are no better, and are even worse than novices, in board positions in which the constituting individual pieces are placed at random (Chase and Simon, 1973; Gobet and Simon, 1996). The reason for this is that the experts' mental representations are based on their experience with real games and real board positions. Hence, their expert knowledge is helpful in those situations, but it does not help, and it even hinders performance, when the knowledge is not applicable (as in random board positions). The use of mental representations that capture configural arrangements rather than single pieces is typical of experts across domains, from forensic fingerprint experts to experts in the recognition of cars, dogs and birds (e.g. Busey and Vanderkolk, 2005; Gauthier *et al.*, 2000; Tanaka and Curran, 2001; Rhodes and McLean, 1990).

The brain changes that occur with expertise reflect the optimization of the brain to carry out the cognitive information processing needed for specific expert performance. As such, the brain adapts, taking advantage of neuronal plasticity. However, as the brain develops to accomplish specific expertise, there are a number of resulting limitations and even degradations that can occur. For example, professional London taxi drivers develop specific brains that underpin their expertise, with greater grey matter volume in the posterior hippocampi (Maguire *et al.*, 2000, 2006). However, such changes in the brain are not mere improvement and enhancement across the board. Along with greater grey matter volume in the posterior hippocampi, Maguire *et al.* found less grey matter volume in the anterior hippocampi. The accompanying behavioural performance levels showed that the London taxi drivers' superior knowledge of London landmarks and their spatial relationships came at a cost of degraded performance in anterograde visuo-spatial memory (see Maguire *et al.*, 2000, 2006). A further study showed that, although London taxi drivers were significantly more knowledgeable about London landmarks and their spatial relationships, they were significantly worse at forming and retaining new associations involving visual information (Woollett and Maguire, 2009).

The same type of trade-offs are apparent in other expert domains. For example, while detecting abnormalities in chest X-rays, expert radiologists show brain activity in the right fusiform face area (FFA) that is correlated with visual expertise. However, it seems that this comes at a price, as activity in left lateral occipital cortex correlated negatively with expertise, and was reduced in experts compared to novices. Hence, achieving expert visual performance may involve developing new neural representations while simultaneously suppressing other existing structures (for details, see Harley *et al.*, 2009). Part of the explanation of some of these brain trade-offs has to do with narrow neural tuning that may accompany specialization and expertise (e.g. Jiang *et al.*, 2007).

Other brain changes reflect higher cognitive mental representations that characterize expertise. For example, Busey and Vanderkolk (2005) studied expert fingerprint examiners and observed brain activity that shows configural processing in fingerprint experts (but not novices). At a higher level of information processing, cognition depends both on bottom-up and top-down information. Bottom-up refers to the incoming data, where as top-down relies on pre-existing knowledge. Top-down has many forms and manifestations, which include the context in which the data is presented, past experience and knowledge, expectations, etc. Experts rely more on top-down information, which allows efficient and effective processing of the bottom-up data, but it can distort and bias how the data are processed. For example, detectives and forensic experts may contaminate and bias investigations because of such top-down processes (see Dror, 2008, 2009; Dror and Cole, 2010).

Experts often consolidate and integrate complex sequences of steps into a unified routine and schemata. By chunking steps together into a single entity or action, the experts not only achieve quick performance in terms of execution time, but they are able to do more because these processes are more computationally efficient. Such mental representations and information processing many times give rise to *automatization* (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977). Experts rely on such processes especially in domains that require complex decisions and actions under time pressure and risk. Automaticity is so efficient that many times it does not require conscious initiation or control, and it may even occur without awareness (Norman and Shallice, 1986).

Once the experts acquire the automated skills, they can perform them effortlessly. However, the change in processes also degrades performance in a number of ways. Given the nature of automaticity, experts cannot fully account and explain, or even recall, their actions. This makes training difficult, as the expert knowledge is not accessible. It is further problematic in expert domains, such as policing and medicine, where accountability is expected and important. The lack of accessibility to knowledge in expert automaticity is so engrained and inherent to the process that trying to access it can reduce performance efficiency (e.g. Beilock *et al.*, 2002; Flegal and Anderson, 2008).

Automaticity that often accompanies the development of expertise can also degrade performance because it introduces different types of slips (Norman, 1981). An expert can make a slip because an uncontrolled automated process has taken place rather than what was actually needed, which may result in expert errors (Reason, 1979, 1990). The lack of conscious awareness and monitoring, as well as lack of control, bring about *rigidity and minimize mindfulness* (Langer, 1989). Expert performance many times requires flexibility and creativity, but with automaticity it is reduced (if not eliminated altogether), resulting in degradation of expert performance (e.g. Frensch and Sternberg, 1989).

Many times experts are required to act very quickly, without time to fully and logically consider all options. These situations entail, at best, minimal flexibility and creativity (whether it is needed or not), as they require very rapid responses (such as in the military, police and medical settings). Actions in such situations rely on 'experiential' knowledge and decision-making brain mechanisms, whereas other situations enable individuals to process and consider information in a more 'analytic' fashion, utilizing different brain structures and decision-making mechanisms (Dror, 2007; Johnson, 1988; Reyna, 2004; Sloman, 1996).

Experts have better 'intuitive' experientially based decision mechanisms, but these may be problematic (Kahneman and Klein, 2009). These mainly develop on the job, through hands-on experience.

As we have seen, many of the underpinnings of expertise involve ways of dealing with cognitive load. They enable the experts to 'do more for less', that is, achieve higher levels of performance with less cognitive effort, giving them enhanced cognition. *Selective attention* is another way of achieving expert-level performance. In fact, one of the most important characteristics of expertise is the ability to pay attention and focus on the important information while filtering out and ignoring the rest (e.g. Wood, 1999). As one becomes a greater expert, one becomes more selective, filtering out more and more information, at an ever-increased rate. While a novice is still trying to absorb the information and make sense of it, the expert has already focused on the critical information (e.g. de Valk and Eijkman, 1984), processed it and solved the problem. Training of experts can focus on enhancing the cognitive system's ability to detect and pick up the important information. Earlier in the chapter we described how enhancing unique aircraft features during training increases acquiring expertise in aircraft recognition (Dror *et al*., 2008).

The process of attention and selection of information is critical. Experts must select the 'right' information, and they use their experience and expectations to guide this process. For example, expert radiologists selectively process X-ray films according to clinically relevant abnormalities (Myles-Worsley *et al*., 1988; de Valk and Eijkman, 1984). This results in efficient and effective processing. However, the superior selective processing of the expert radiologists is restricted to abnormalities, and was associated with degradation in their ability to detect variations in normal features that did not contain abnormalities. Moreover, selection processes are also highly vulnerable to biases and to other functional degradations.

What happens, for example, when experts filter out and ignore important information because they regard it as irrelevant? Imagine a police detective gathering information in a criminal investigation, guided by expectations that a certain suspect is guilty. If the expectation or 'hunch' is correct, then information is effectively filtered out; however, if they are incorrect, then important information is ignored (Dror, 2008; Rossmo, 2008). Such confirmation bias is more likely to cause an expert to notice and focus on information that validates and confirms their expectation, extraneous information, context, a belief or a hope. These affect the way the expert allocates attention and examines information. The result is possible degradation in performance, since confirming data are weighted highly and emphasized, while conflicting data are weighted low (sometimes even filtered out and ignored altogether).

Dror and Charlton (2006) and Dror *et al.* (2006) examined potential expert error in the domain of forensic fingerprinting. In a couple of studies, expert fingerprint examiners were presented with prints and were required to determine whether the prints matched. Unknown to the experts, they were in fact presented with fingerprints they had judged in the past, and the experimental set-up was designed to examine if performance would degrade because of extraneous contextual cues. For example, fingerprints that were matched as a definite identification by an examiner a few years ago were re-presented to the same expert examiner as normal routine criminal case work. However, when the prints were re-presented, they were presented within an extraneous context that suggested that they were not a match (e.g. someone else confessed to the crime). Many of the expert examiners contradicted their own past conclusions, exhibiting degradation in performance, and resulting in erroneous conclusions as a result of the contextual influences (see Dror and

Charlton, 2006; Dror *et al.*, 2006; Dror and Rosenthal, 2008 for details). Such findings are not limited to forensic examiners, e.g. see Potchen (2006) for inter-observer variability among radiologists, and Patel and Cohen (2008) for general medical errors in critical care.

One of the main themes of this paper is to demystify expertise. Taking experts off the high pedestal and examining expertise from a scientific viewpoint, showing that expertise is not 'all good', and demonstrating the existence of paradoxical functional degradation with expertise (e.g. Hecht and Proffitt, 1995). I have focused on cognitive and brain elements of expertise, such as unitization, configural processing, automaticity and attention. However, there are other psychological effects that can degrade the performance of experts. For example, over-confidence, and sometimes even arrogance, can be an Achilles heel of experts. As they become greater and greater experts, their confidence increases. This can result in refusal to listen to others, take advice, pay attention to detail, etc. This is especially problematic in expert domains that involve risk-taking and uncertainty. For example, a doctor who is over-confident may not follow procedures in detail and take shortcuts; a fighter pilot with over self-confidence may take inappropriate risks; and an over-confident financial banker may make unbalanced and too high-risk investment decisions. Wishful thinking, escalation of commitment, tunnel vision, belief perseverance, cognitive dissonance, group think, and other phenomena can also cause functional degradation with experts (e.g. errors by expert referees of scientific journal articles, see Peters and Ceci, 1982; Rothwell and Martyn, 2000).

To summarize, I have tried to illustrate the paradoxical nature of expertise, showing that with extraordinary abilities come vulnerabilities and pitfalls (e.g. Dror *et al.*, 1993; Busey and Dror, 2009). These paradoxical elements represent inherent computational trade-offs in brain and cognitive mechanisms that govern expertise, many of which are unavoidable. The view that experts optimize performance overall is rejected, but rather experts specialize and adapt their cognitive processing, optimizing to certain and specific scenarios, but these changes do not always result in enhanced performance overall. Paradoxically, in some cases they cause performance degradation (e.g. Hecht and Proffitt, 1995). The paradoxical functional degradation of expertise is important to study and understand as it gives a realistic picture of expertise, and also has implications on how to maximize expert performance.

For enhancing expert performance, and minimizing the vulnerabilities that come with it, one can use technology to support and overcome potential weaknesses. By 'off-loading' elements of expertise onto computers, one can extend the expert's ability and distribute cognition more appropriately (Dror and Harnad, 2008). However, throwing technology at experts is by no means a solution – in fact, not only may it not help experts, it may even degrade their performance. How best to use technology to help experts, how to optimize the distribution of cognition and expert–technology collaboration, is a complex issue that has to be carefully considered (Dror and Mnookin, 2010).

Expert performance depends mainly on two elements – the expert and their training. Both elements pose interesting challenges for further research. In relation to the experts themselves, critical factors include how to select the right people for domains in which they can excel, how best to fit the person's ability to the job requirements, and how to take advantage of their cognitive profile and relate it to those cognitive abilities that are needed.

Once you select the right person, then further research can guide the way to how best to train them. The two issues, of selection and training, are related. Abilities that are relatively hard-wired in the brain should be the focus of initial selection and screening, whereas those abilities that can be acquired through neuronal plasticity and, thus, are more trainable should be the focus of training (see Dror *et al.*, 1993; Jiang *et al.*, 2007; Munte *et al.*, 2002; Draganski *et al.*, 2004).

The nature of expertise, its cognitive underpinning and its architecture have been discussed and considered, and pose complex challenges which more research can further enlighten. However, any future steps in improving expert performance must be scientifically guided, with an understanding of the vulnerabilities of experts (the enhanced performance along with the potential pitfalls), and not through the naive view that experts are merely superior.

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