out random noise. However, not all trial-wise variation is noise. In many circumstances, trial-wise averaging will also cancel out important signals. Consider Galton's [10] bean machine (or 'quincunx'): a marble falls down a board with many pins and with each hit of a pin the marble has a 50% chance of falling to either side of that pin. At the bottom of the board are several buckets, one of which will catch the marble at the end of its fall. By the central limit theorem, the distribution of marbles in the buckets will tend towards a Gaussian distribution. While this is a useful and important characterisation of the data, it does not help us understand how any particular marble ended up in its particular bucket; the history of the individual marble is lost in the average. For the next big step forward in cognitive neuroscience, we need to focus on the equivalent of individual marbles hitting individual pins: real-time single-trial dynamics.

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Forum

Conjuring Deceptions: Fooling the Eye or Fooling the Mind?

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Currently, we see the contours of a new research program emerging, where cognitive scientists study what magicians do and why it works. This research program may aid us in formulating interesting questions about central aspects of human experience and in gaining new perspectives on the relation between perception and cognition.

The study of illusions as a window into the mechanisms underlying perception and cognition is one of the main methodological tools of cognitive science. Thus, the stunning illusions produced by professional magicians are of great interest to cognitive scientists [1–3]. Perhaps even more importantly, however, thinking about magic from the practical perspective of the magician may reveal theoretically interesting questions that are otherwise less obvious.

Magicians are sometimes referred to as illusionists, but their ultimate aim is to design miracles, not mere illusions [4]. That is, the magician's first question is how they can create the illusion of impossibility [3,4]. Relatedly, the magician's second question is how they can make sure that nobody is able to figure out how it was done. That is, they are essentially aiming to construct a problem that is as difficult to solve as possible, given the fundamental principles of human problem solving [5].

These two simple practical questions are probably not frequently pondered in academic cognitive science, but they may turn out to be of considerable heuristic value.

The Formation of Mutually Contradictory Beliefs

Experiencing something as impossible implies that one must hold two beliefs that contradict each other. Furthermore, if either of them is not experienced as absolutely certain, the impossibility is ruined. Thus, the magician's first question immediately taps into the question of what are the sources of strong beliefs. Furthermore, since two contradicting beliefs implies that one of them must be wrong, the magician's first question raises the question of how false, yet strong, convictions are best created.

Cognitively Impenetrable Illusions

Being impervious to conscious reasoning (cognitively impenetrable) is considered to be a major hallmark of perceptual illusions [6,7]. Hence, it seems natural to think of perceptual illusions as the ideal answer to the magician's second question.

Yet, in current discussions of the factors underlying the art of conjuring, the classical perceptual illusions have a relatively minor role [1,3]. How can this be reconciled with the above reasoning? We believe that the contradiction is only apparent: magicians do in fact rely on perceptual illusions to a considerable extent, but our traditional scientific notions about what should count as a perceptual illusion are too limited for two reasons. First, some of the achievements of the perceptual system, such as inferences about causality, intentions, reality, or occluded scene regions, are so staggering that it is difficult to envision that they are not due to more 'intelligent' high-level cognition. Second, the introspectively obvious fact that we consciously reason about these things suggests that there is no role left for the perceptual system in making inferences about them.

Perception and Cognition, together and apart

As an example of how easy it is to overlook the role of perception, consider how we experience parts of a scene that are hidden from direct view. Since these hidden parts do not produce any retinal stimulation, it would seem self-evident that they must be a product of mere cognitive guesswork or imagery. Yet, research on amodal completion [8] shows that perceptual mechanisms are nevertheless involved in shaping our experience of hidden scene regions. This can explain why many magic tricks are more robust than one might intuitively expect. In the multiplying balls trick [7,9], for instance, the magician fools the audience by using a semi-spherical shell that looks like a complete ball (Figure 1). Importantly, the audience does not merely entertain the intellectual belief that the semi-spherical shell is a complete ball, but rather automatically and immediately perceives it as such [7,9].

This example illustrates two important points: first, both conscious reasoning and perceptual mechanisms may be involved in solving the same problem (in this case to infer the shape of the hidden parts of a visual scene). Normally, the results of cognition and perception agree, but under special conditions, they contradict each other, making a bit of the world appear to us 'in a way we know is not or cannot be the case but which, despite such knowledge, appears this way repeatedly and incorrigibly' ([10] p. 186). Only then does the involvement of perceptual mechanisms become evident. Second, the perceptual system may be involved in making inferences about very abstract 'high-level' properties of the world that go far beyond the available sensory input.

There is good reason to believe that perceptual mechanisms have an equally important role in several of these high-level domains: (i) Causality: most of the techniques used by magicians to hide the true cause of the supposedly magical effect rely on manipulating factors that are known to trigger genuinely perceptual impressions of causality, in particular temporal and spatial proximity of cause and effect [4]. For instance, magicians often perform magical gestures, such as

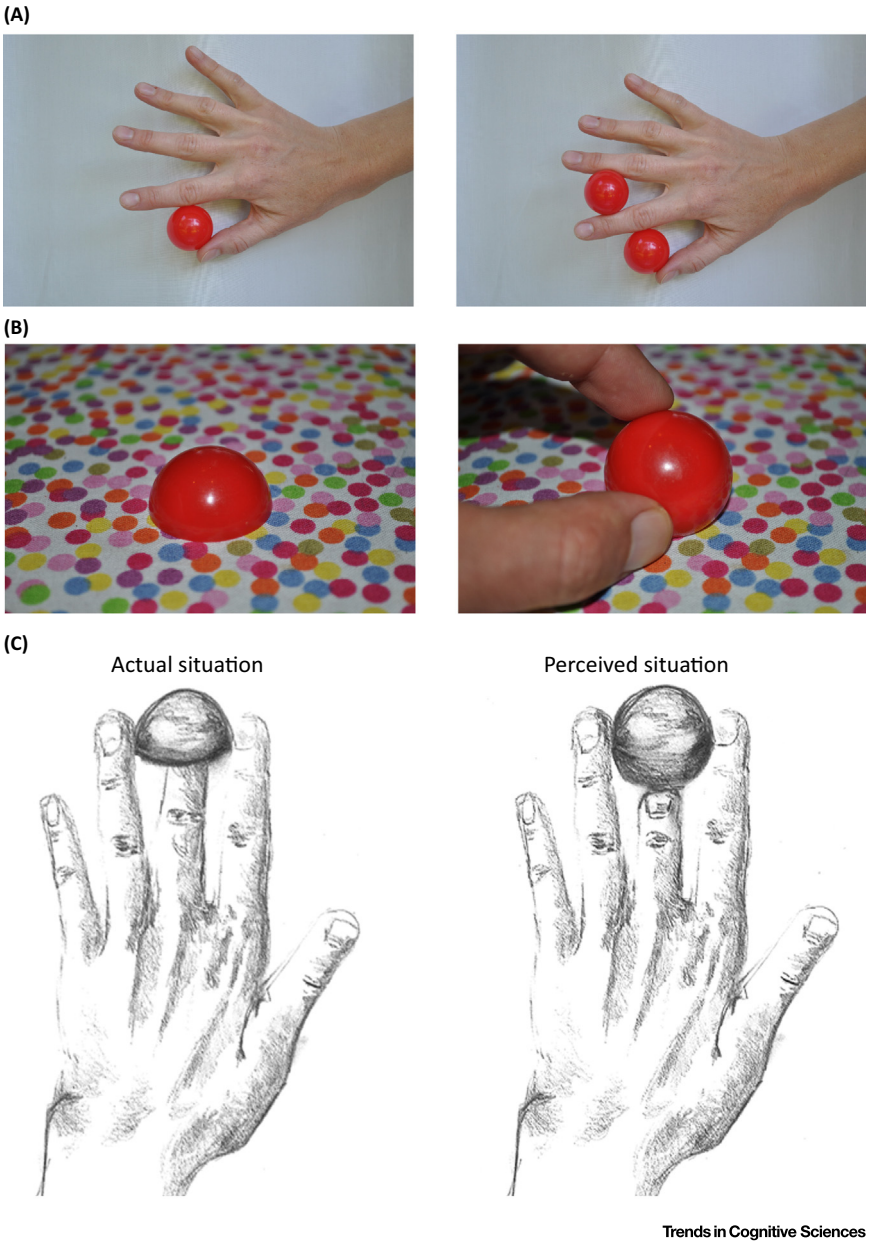

Figure 1. The Magical Force of Amodal Volume Completion. In the multiplying balls routine (A), the magician first shows what seems to be a single complete ball (left). After a quick flick of the wrist, a second ball magically appears (right). The secret behind this trick is that one of the 'balls' is in fact a hollow semi-spherical shell, in which the real ball is first kept hidden. Despite the simple method, it is difficult for naive observers to figure out the secret behind the trick [5]. The observations illustrated in (B) and (C) suggest that this is because spectators do not merely entertain the intellectual belief that the 'balls' are all solid, but rather automatically and immediately perceive them as such [7,9]: simply lifting a semi-spherical shell up from the table (B) immediately makes it look like a complete ball. Putting your finger into such a semi-spherical shell and viewing it from above (C) makes the finger feel shorter, as if to make space for the illusory ball [9]. Reproduced from [7] (A,B).

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