doi:10.1038/nature12704

PSYCHOLOGY

Good and bad news on the adolescent brain

In response to bad news about risk, young adolescents alter estimates of their own vulnerability to adverse events less accurately than older people. The finding has implications for managing risk-taking behaviour in young people.

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Winston Churchill once referred to Russia as "a riddle wrapped in a mystery inside an enigma". Adolescence could be described in the same way. Adolescents are at the peak of physical robustness, yet they are also at an elevated risk of death, injury and disease. Much of this increased mortality and morbidity has been blamed on risky decision-making processes performed by a still-maturing brain[1]. Massive public-health campaigns and educational efforts have been aimed at reducing unhealthy risk taking, and have generally focused on exposing adolescents to information about the adverse health consequences of risky behaviours. Writing in *Proceedings of the National Academy of Sciences*, Moutsiana *et al.*[2] present a study that raises questions about how effective all of this 'bad news' is in teaching adolescents to update their risk estimates.

Previous research has shown that adults are more likely to incorporate good news than bad news into their beliefs. For example, news that a genetic mutation places them at lower risk of cancer than they thought is more likely to alter an adult's belief about his or her cancer risk than is news of a mutation that puts them at higher risk. Moutsiana and colleagues have now examined this process of belief updating in response to good and bad news in individuals aged from 9 to 26 years, a period during which the brain is maturing. The participants were presented with 40 adverse events and asked for their estimates of personal risk — how likely (as a percentage) the event was to happen to them in the future. Then, the actual likelihood was presented and, in a second session a few moments later, they re-estimated their personal risk of the same events (Fig. 1).

The researchers found that updating beliefs about risk did not change significantly with age for good news (when participants were at a lower risk of an adverse event than they thought). But information about being at a higher risk — bad news — was correlated with age, such that beliefs were not sufficiently updated in younger participants. The gap between learning from good versus bad news narrowed with age. The authors controlled statistically for a host of alternative explanations for these age differences, including prior beliefs and past experience with the events. They also ensured that the youngest respondents understood the concept of percentages and that none of the respondents was depressed, which could have produced differences in responses to negative events.

In the brain, dopaminergic neurons are activated in response to outcomes such as rewards; in particular, they signal the discrepancy between expected and actual rewards — referred to as prediction-error signals. Moutsiana *et al.* argue that the good–bad differences they document originate in an asymmetry in the development of dopaminergic responses to prediction-error signals. In fact, hyper-responses to rewards in the striatum region of the brain (a rewards area) peak during adolescence[3], although some research suggests[4] that adolescents are hyporesponsive to rewards. By contrast, activity in the brain's prefrontal cortex region (a cognitive-control area), specifically the inferior frontal gyrus, is associated with updating beliefs to negative errors in this estimation task.

Moutsiana *et al.* also recorded an important developmental difference in individuals' memories of the presented risk information, assessed by asking the participants the presented actual probability at the end of the sessions. They found that misremembering was related to age for both good and bad news, with younger participants remembering less accurately. Furthermore, memory for risks correlated with updating of risk estimates across the age range. Nevertheless, although such memory differences influence risk perception and behaviour[5], they do not explain the good–bad differences observed in this study.

Much of the research on adolescent risk taking, including this study, is steeped in theories of neo-Freudian dualism, in which the prefrontal cortex (Sigmund Freud's 'super-ego') suppresses the urges of an instinctual limbic system (the 'id'). But this latest work highlights the often-neglected issue of learning. In an earlier generation of research, learning was the centrepiece of psychology — generally speaking, to be a psychologist was to be a learning theorist. Learning also offered the hope of change, by definition, because learning involves an alteration in knowledge or beliefs.

Current theories of the adolescent brain rightly emphasize socio-emotional development[6], but one lesson from Moutsiana and colleagues' study is that cognitive and

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Figure 1 | Adverse events. Moutsiana *et al.*[2] studied how adolescents' estimates of their own risk of experiencing an adverse event, such as a broken bone, changed in response to information about their actual risk.

motivational changes from childhood to adulthood are intertwined. Learning, which is a cognitive faculty, occurs for positive and negative information, but it occurs differently depending on motivational salience (people are more motivated to believe good news than bad news).

This work opens the door to many questions about risk perceptions and their effect on behaviour. Like many others in the field of risky decision-making, this study extracts numerical risk estimates from participants and provides them with other such estimates. How do we know that a person understands his or her personal risk? We ask them to parrot a probability. Although there are advantages to this method (for example, it permits intriguing analyses of calibration and updating), it ignores a basic psychological truth about risk estimates: that the estimates used by people in the real world to guide their behaviour are mentally represented not as precise quantities but as qualitative gists, such as 'a really high risk'[7]. Researchers in medical decision-making and public health have come to realize that simply remembering and repeating a number verbatim does not capture how most people represent risk in their minds and brains[8–10].

Moutsiana and colleagues' exciting findings highlight the related concept of the emotional gist of risk information, which is likely to colour intuitions about risk differently across the lifespan[11]. The riddle of adolescent risk taking may not be solved any time soon, but we are seeing a great leap in scientific knowledge about this topic, with broad implications for enhancing public health and well-being. ■

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1. Reyna, V. F. *et al. J. Exp. Psychol. Learn.* **37,** 1125–1142 (2011).
2. Moutsiana, C. *et al. Proc. Natl Acad. Sci. USA* **110,** 16396–16401 (2013).
3. Casey, B. J. *et al. Proc. Natl Acad. Sci. USA* **108,** 14998–15003 (2011).
4. Bjork, J. M. *et al. J. Neurosci.* **24,** 1793–1802 (2004).
5. Mills, B., Reyna, V. F. & Estrada, S. *Psychol. Sci.* **19,** 429–433 (2008).
6. Strang, N. M., Chein, J. M. & Steinberg, L. *Front. Hum. Neurosci.* **7,** 223 (2013).
7. Reyna, V. F. *Med. Decis. Making* **28,** 850–865 (2008).
8. Peters, E. *Curr. Dir. Psychol. Sci.* **21,** 31–35 (2012).
9. Reyna, V. F. & Huettel, S. A. in *The Neuroscience of Risky Decision Making* (eds Reyna, V. F. & Zayas, V.) 11–42 (Am. Psychol. Assoc., in the press).
10. Zikmund-Fisher, B. J. *Med. Care Res. Rev.* **70,** 37S–49S (2013).
11. Tymula, A. *et al. Proc. Natl Acad. Sci. USA* **109,** 17135–17140 (2012).