Part III

Ethical, philosophical, legal, and policy issues of cognitive enhancement

Chapter 11

The evolutionary limits to neuroenhancement

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11.1 An evolutionary paradox

According to a recent, but possibly already outdated estimate, "more than 100 drugs are currently being developed, tested or used for cognitive enhancement" (Förstl 2009, 841). The psychoactive substances under investigation include cholinesterase inhibitors, memantine, dimebon, ampakines, fluoxetine and other antidepressants, methylphenidate, and modafinil. All of these substances are being considered for use as neuroenhancers in healthy individuals (Förstl 2009), with potential advantages for attention, memory, motivation, creativity, and alertness. It is also speculated that psychoactive substances may be able to improve moral decision-making, relationships, and longevity in healthy people (Earp et al. 2012; Finkel and Holbrook 2000; Persson and Savulescu 2012). On the surface of things, neuroenhancers thus seem to offer vast potential for improving human life.

According to media coverage, this message has not fallen on deaf ears. Numerous reports have suggested that the use of prescription drugs to improve cognitive and psychological functions—neuroenhancement—in healthy people is "common, increasing in prevalence, or both" (Partridge et al. 2011, 4). Beyond the media hype, however, representative surveys suggest that neuroenhancement is not (yet) the norm. For instance, German surveys of the general population, student populations, and employees gauge the prevalence of neuroenhancer use in healthy individuals to be about 1.5 to 5% (Kowalski 2013). Yet while these numbers are much smaller than those broadcast by the media, they still translate into an estimated two million employees in Germany using psychoactive drugs for nonmedical purposes.

This purported rise in pharmaceutical self-enhancement represents a potential sea change in the way the general public and, to some extent, scientists view cognition. In the past, cognitive ability was conceptualized as a nearly fixed quantity, one that people essentially have to live with until it inevitably declines with age. To the extent that there is plasticity, it was assumed that cognitive abilities could be boosted only through diligent practice involving great effort (e.g., Kliegl et al. 1989). Neuroenhancement, in contrast, bears the promise of made-to-order, off-the-shelf optimized cognition. It promises to make people smarter, more alert, more focused, or more persistent—and that these gains come without pain. As the old adage goes, however, "there's no such thing as a free lunch." In this chapter, we explore the hidden cognitive costs of neuroenhancement. By hidden costs, we do not mean the potentially serious and unanticipated medium- and long-term health consequences of extended use of psychoactive substances (e.g., Förstl 2009); neither do we mean the many ethical issues associated with the rise of neuroenhancement (e.g., Farah 2005). Our starting point is a different one: If enhancers are truly beneficial, why have the respective cognitive capacities not been developed through evolution?

Adaptationist accounts of evolution posit that, in proportion to the selective pressures from the environment, evolution will optimize over constraints and produce phenotypes that are close to optimal (Pigliucci and Kaplan 2000). The bolder the claims made about enhancement, the more likely it would seem that the capacities being targeted should already exist. If they offer competitive advantages to the organisms that have them, then natural selection should have favored them. With the potential of pharmacology to improve school performance, reduce age-related cognitive decline, improve human performance in combat, and even enhance scientific productivity (e.g., Greely et al. 2008), it is almost too easy to overlook the question of why these capacities have not been developed through evolution (see, e.g., Humphrey 2002). If these enhancements are so promising and powerful, it seems doubly important to understand why humans are not yet endowed with them.

One possible answer from an evolutionary perspective is that the notion that cognitive capacities can be enhanced at no cost rests on a naïve "more-is-better" assumption. More memory is better; more focus is better; more happiness is better; more self-control and willpower are better; and so on. Just as people cherish faster processing speed and larger memory in their digital electronics, they may assume that boosting a particular cognitive trait will bring better mental performance and affective well-being. As we discuss in this chapter, however, the empirical evidence indicates that in many domains the more-is-better assumption is incorrect. Unfortunately, both users of neuroenhancers and some of their scholarly advocates seem to buy into this assumption. Claims that "the drugs ... should be viewed in the same general category as education, good health habits, and information technology" (Greely et al. 2008, 702), for example, appear to rest on this naïve and erroneous view of cognition.

Admittedly, numerous technological additions to modern life can be viewed as enhancers of cognition—pencils, books, and computers can all help to improve decision-making and quality of life. The same applies to enhancers of cognition that target the representation of information and knowledge in the world: presenting information in ways that are more easily processed can help to improve the statistical reasoning and decision-making of patients, doctors, lawyers, and the public more generally (e.g., Hoffrage et al. 2000). How is a pharmacological nudge any different? From an evolutionary perspective, the difference is profound. Education, health habits, computers, and information presentation formats are subject to horizontal (i.e., cultural) transmission. They have not been around long enough, nor has the selection pressure been strong enough, to lead to evolutionary changes at the level of the genome.

Cultural changes do affect cognitive faculties and can improve cognitive performance. Indeed, systematic gains in human intelligence—both crystallized and fluid—have been observed since the middle of the past century in most of the developed world (Flynn

2012). The proposed explanations for these changes are cultural in origin; predominantly knowledge-based accounts explain the gains in terms of improvements in, for example, abstract reasoning and analogy (Flynn 2012; Fox and Mitchum 2013). The possibility that the gains could be evolutionary in origin is flatly discounted, because the time scale over which the changes have taken place is simply too short.

However, the targets of neuroenhancement—e.g., attention and memory—*have been* subject to selection. Evolution has had thousands, if not millions, of years to fine-tune these cognitive traits. If evolution has not adapted them to the environment, the question is why. One may argue that today's environment is sufficiently different from the ancestral environment to warrant additional tuning. We briefly return to this caveat in section 11.3. Yet it is deeply curious that some single-gene mutations appear to enhance memory and cognition, but do not appear to have been selected for in wild-type populations. Seemingly trivial neuromolecular changes, such as the overexpression of *N*-methyl-D-aspartic acid (NMDA) receptors in the hippocampus, appear to enhance memory (Tang et al. 1999). Mutant mice lacking the nociceptin receptor also show improved learning and memory (Manabe et al. 1998), as do mice lacking the α5 subunit of the $GABA_A$ receptor (Collinson et al. 2002). Given the likely ease with which evolution could have accessed these mutations, their absence in wild-type populations is difficult to reconcile with their apparent added value. Something is amiss.

The resolution of this evolutionary paradox is the focus of this chapter. In particular, we consider why cognitive capacities have evolved to their currently observable state. Our explanation requires an understanding of the constraints (or trade-offs) under which cognitive traits have evolved. Without such trade-offs, selective forces associated with improved performance (and thus fitness) would drive the performance capacities of cognitive traits ever upward. As we explain later, however, all known evolutionary trajectories inevitably run up against constraints that prevent such runaway selection. The costs eventually outweigh the benefits. So which evolutionary trade-offs are built into the cognitive system and where do they come from? In what follows, we discuss two kinds of evolutionary trade-offs that must be considered in the context of neuroenhancement. We then briefly provide theoretical and empirical evidence for an alternative to the more-is-better view of human cognition and decision making. Finally, we outline what follows from the evolutionary view that we propose in this chapter.

11.2 Evolutionary cognitive trade-offs

The evolution of any living system is the result of trade-offs over multiple constraints. Consider the human female pelvis. Because its dimensions are small relative to a baby's head, obstetric complications during labor are common. Why hasn't evolution improved the survival chances of both mother and baby by selecting for a larger female pelvis? The widely accepted explanation is that the optimal pelvis for bipedal locomotion and the optimal pelvis for encephalization (the progressive increase in the baby's brain size) place competing demands on the human pelvis. Bipedal locomotion requires substantial skeletal changes, including alterations in the pelvic architecture (Wittman and Wall 2007), and such changes must compete (in an evolutionary sense) with the obstetric demands of human babies' relatively large brains. Recent evidence suggests that this limit may be still more complicated, involving metabolic demands on the mother, who is unable to cope with babies above a certain size (Dunsworth et al. 2012).

Cognition is the product of similar trade-offs over multiple constraints. Notably, these constraints originate from two different sources: (1) the kinds of problems a flexible intelligence has evolved to solve and (2) the underlying biology. These two kinds of constraints generate within-domain and between-domain trade-offs, respectively. These trade-offs have typically been confounded in the literature on enhancement, but their distinctness is evident in the ubiquity of *inverted U-shaped performance functions* (henceforth ∩-shaped performance functions) and the *side effects* of enhancement (Cools and Robbins 2004; Husain and Mehta 2011), respectively. These two kinds of trade-offs explain why we are not smarter than we are.

11.2.1 Trade-offs within domains: ∩-shaped performance functions

Performance functions that are ∩-shaped are often observed for optimal-control problems in which the goal is to maximize benefits subject to some cost function (i.e., specified constraints). Such problems often require a decision on when to stop taking one action and switch to another. Specific examples include when to accept a particular job candidate or mating partner rather than to continue looking for another; when to leave one resource patch to move to another; and when to stop collecting information and make a decision. Cognition must solve these kinds of attention-switching problems in countless domains that combine poorly defined completion criteria (i.e., in which it is unclear when to stop) with opportunity costs (Hills et al. 2010). Furthermore, even in problems that provide well-defined completion criteria, there may be multiple possible trajectories to a solution, and finding a solution may involve abandoning an approach that is not working.

Myriad cognitive problems of organisms from nematodes to office workers have been formulated as optimal-control problems (e.g., Pirolli 2007). The ecological regularity of such problems has led to the proposal that regulating goal maintenance and abandonment (i.e., persistence in action) is one of the key evolutionary building blocks leading to the flexible intelligence associated with executive cognition (Hills and Dukas 2012). For support, this proposal points to the shared structure of control problems across domains and the shared neural correlates and cognitive function of the processes that solve these problems across species. As one example, domain-general cognitive-control processes related to working memory span are governed by attentional control and updating (see Unsworth and Engle 2007). These control processes, by their nature, influence how attention is distributed over potential goals in an environment.

Mathematically, optimizing the control of attention over opportunity costs can be reduced to a search problem, in which cognition attempts to maximize its payoff by choosing how long, t^*, to perseverate on one action or goal state before switching to another.

With the realistic assumption that any course of action is associated with reduced payoffs over time, $F(t^*)' < 0$, and that it costs some amount of time, T, to switch between actions, the optimal t^* solves the equation

$$F(t^*)' = \frac{\bar{F}(t^*)}{t^* + T}$$

where $\bar{F}(t^*)$ is the mean payoff associated with all other action payoff functions. In words, the giving-up (or abandonment) rate, $F(t^*)'$, associated with one action should be related to the opportunity costs associated with switching to other possible actions. For any problem that fits this basic framework, an ∩-shaped performance curve arises naturally over the values of t^* (see Figure 11.1). Given that problems of optimizing over subgoals make up a significant portion of real and laboratory cognitive tasks (e.g., Tower of London, category fluency, and operation span), one should expect to find ∩-shaped dose-response curves among people who have taken pharmaceuticals designed to increase the duration of focused attention, t, with respect to a given task.

For illustration, consider the following accuracy-effort trade-off faced by a chess player planning her next move. The time to investigate future moves is limited (e.g., at tournaments, each player often has not more than 2 hours to make the first 40 moves). Constrained by the capacity to investigate only one sequence of future moves at a time, the player has to solve the problem of how long to investigate any one sequence of moves. She may choose to move her pawn first, which she anticipates will be met with the opponent

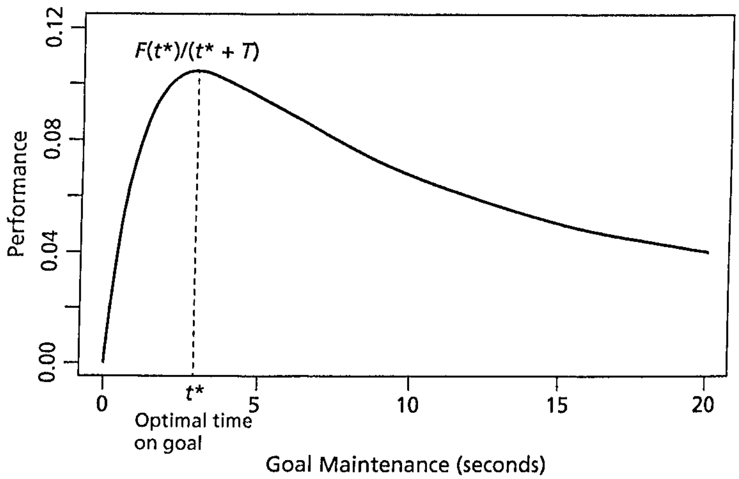

Figure 11.1 Optimal allocation of attention to a goal state. Performance scores associated with resource intake per unit time are optimal when the local goal, attending to a specific target or action, is maintained for an intermediate value of time, t^*, before the subject switches to a new action with a similar cumulative payoff function. For visualization purposes, we let $T = 5$ s and $F(t) = 1 - e^{-0.6t}$.

playing their rook, followed by her playing her knight, and so on. But how long should she continue down this route? The longer she investigates this sequence, the less time she will have to investigate alternatives. If she investigates many alternatives, she will know little about the long-term consequences of any of them. Yet the cost of thoroughly investigating only a few alternatives is that she may overlook better ones. There are many facets to being a good chess player, but a key one is the capacity to optimize the trade-off between too little and too much exploration of a given sequence of moves. As in Figure 11.1, the best solution lies somewhere in between.

The importance of striking a balance between too much and too little is not just theoretical, but relates directly to research on neuroenhancement. Consider amphetamines, Ritalin, and modafinil, all of which have been proposed as neuroenhancers of attention. These drugs exhibit some positive effects on cognition, especially among individuals with lower baseline abilities. However, individuals of normal or above-average cognitive ability often show negligible improvements or even decrements in performance following drug treatment (for details, see de Jongh et al. 2008). For instance, Randall et al. (2005) found that modafinil (a drug licensed for the treatment of narcolepsy and sleep apnea) improved performance only among individuals with lower IQ, but not among those with higher IQ. Similarly, Mohamed (2014) showed that, after taking modafinil, participants low in the personality trait of creativity scored higher on a convergent thinking task of creativity than did those scoring high on this trait. In addition, modafinil appeared to reduce divergent creative thinking in the same participants. Similarly, Farah et al. (2009) found a nonlinear relationship of dose to response for amphetamines in a remote-associates task, with low-performing individuals showing enhanced performance, but high-performing individuals showing reduced performance. Such ∩-shaped dose-response curves are common (see Cools and Robbins 2004). More importantly, they demonstrate that improving attention is much more complicated than simply giving individuals the capacity to increase their focus.

11.2.2 Trade-offs between domains: cognitive side effects

Within-task trade-offs represent a key constraint on both the evolution and the pharmacological enhancement of cognition. However, even when within-task trade-offs can be avoided, between-task trade-offs may remain. The reason is interdependencies across domains. Recall our example of the female pelvis. Expanding the birth canal would reduce the likelihood of obstetric complications, but at the expense of efficient bipedal locomotion. Such interdependencies apply across cognitive domains as well as between cognition and other more general domains, such as mental and physical health. One common example is the rise in anxiety and loss of fine motor control often found following high doses of caffeine (Smith 2002). By the same token, the enhancements to memory and attention associated with nicotine (Warburton 1992) have well-documented long-term effects on mortality and health (Rostron 2013).

It has been controversially argued that the Ashkenazi Jew population provides a less well-known, but more dramatic example of between-domain trade-offs (for all arguments in this paragraph, see Cochran et al. 2005; Cochran and Harpending 2009; and also Pinker 2006 for a critical review). Among Ashkenazi Jews, the average IQ is approximately 0.7 to 1 standard deviations above that of the general European population. According to Cochran and colleagues, this rise in IQ may have been the consequence of evolutionary selection for greater intelligence among Ashkenazi Jews in medieval Europe. However, this greater cognitive capacity appears to have exacted costs on other dimensions. In particular, although Ashkenazi Jews perform better on verbal and mathematical tests, they perform roughly half a standard deviation below the European average on visuospatial abilities. Perhaps more importantly, sphingolipid disorders such as Tay-Sachs, Niemann Pick, Gaucher, and mucolipidosis are more prevalent in this population. These diseases are correlated with the same neural causes that rendered increased IQ possible, such as increased dendrite development.

Cases of individuals with superior memory provide additional examples of cognitive trade-offs. Parker et al. (2006) reported on the case of a woman, AJ, who described her memory as "non-stop, uncontrollable, and totally-exhausting" (p. 35). Tests showed her to achieve perfect or near-ceiling performance on visual memory, visual paired associates, word recognition, autobiographical memory, and digit span. However, AJ's performance on tasks of executive function and reasoning were impaired. For example, on the Wisconsin Card Sorting Test—a task that requires adaptive switching to new contexts—AJ showed abnormal levels of perseveration on past rules. She also showed impaired performance on a face recognition test. Moreover, AJ's enhanced memory performance did not translate into outstanding school grades. She explained that her memory—although prodigious—was "automatic, not strategic," and therefore of limited use in willful memorization.

Similar accounts of memory and other cognitive trade-offs are found for people with synaesthesia, which is the experience of cross-modal associations—for example, seeing the color yellow when hearing the number 4. Individuals with synaesthesia often show enhanced memory for numbers and words (Yaro and Ward 2007). However, they also often have deficits in mathematical and spatial reasoning (Cytowic 1995; Rothen et al. 2012). Luria's (1987) famous examination of a man named Shereshevskii, whose memory appeared to have "no distinct limits" (p. 11) and in whom Luria diagnosed an extremely strong version of synaesthesia, offers another illustration of the potential costs of perfect memory. For instance, the experience of cross-modal associations caused Shereshevskii difficulties in daily life:

> One time I went to buy some ice cream ... I walked over to the vendor and asked her what kind of ice cream she had. "Fruit ice cream," she said. But she answered in such a tone that a whole pile of coals, of black cinders, came bursting out of her mouth, and I couldn't bring myself to buy any ice cream after she had answered in that way. (Luria 1987, 82)

Even more profoundly, he had problems extracting the meaning of simple passages of text and especially of poetry or metaphors. In Luria's (1987) words, he

> was unable to grasp an idea unless he could actually see it, and so he tried to visualize the idea of "nothing", to find an image with which to depict "infinity". And he persisted in these agonizing

> attempts all his life, forever coping with a basically adolescent conflict that made it impossible for him to cross that "accursed" threshold to a higher level of thought. (Luria 1987, 133)

The paradox of near-perfect memory paired with comprehension deficits bedeviled Shereshevskii. Similar paradoxes are often experienced by savants, who offer perhaps the clearest natural evidence for between-domain trade-offs in performance across tasks. Their spectacular skills in one domain go hand-in-hand with poor performance in other domains (Treffert 2009). This is no coincidence. Savant-like skills can be induced in healthy participants by *turning off particular functional areas of the brain*—for example, via repetitive transcranial magnetic stimulation (Snyder 2009).

11.3 **More capacity is not invariably better**

What is the origin of the more-is-better assumption that is the leitmotif of the enhancement venture? One can only speculate, but one source may be psychology's portrayal of the human mind as profoundly limited—a view that emerged in the second half of the twentieth century. Our brain has been weighed, measured, and found wanting. In research on memory, for instance, the list of documented limits includes the now classic thesis that the number of "chunks" of information that can be stored in short-term memory is restricted to the magical number of seven, plus or minus two (Miller 1956); more recently, this number has been trimmed to just four chunks (Cowan 2001). In research on attention, the influential filter theory (Broadbent 1958) envisioned a limited transmission capacity that requires a filter to protect the human information processing machinery from overload. Kahneman (1973) replaced the filter by a supply metaphor, in which attention is an unspecified capacity ("energy") that, due to its limited nature, must be strategically allocated. More recently, Pashler (1998) revived the filter theory and argued that such a filter acts as a central bottleneck in decision-making and memory retrieval. Still others have proposed that the human budget of strategic processing capacity is restricted (e.g., Schweickert and Boggs 1984), and that the ability to pursue multiple intentional goals at any one time is therefore limited. This list of limitations goes on and on.

The view that the human capacity to process information is limited is often accompanied by another assumption, namely, that these limitations pose a liability (see Hertwig and Todd 2003). They restrict people's cognitive potential, barring them from performing feats such as computing the square roots of large numbers in their heads or reciting all of Shakespeare's sonnets by heart. More sinister still, these cognitive limitations are suspected not only of undermining performance, but also of thwarting the ability to reason, judge, and decide rationally. The close link between cognitive limitations and suboptimal reasoning is made in such varied psychological research programs as Piaget's theory of cognitive development in children (e.g., Flavell 1985), Johnson-Laird's mental model theory (1983, 2001), and Kahneman and Tversky's influential heuristics-and-biases program (e.g., Kahneman et al. 1982). The latter, for instance, assumes that people, weighed down by their cognitive limitations and pressed to make decisions in a complex and uncertain world, are often unable to reason and decide rationally (i.e., in agreement with the norms of probability theory, rational choice theory, and statistics). Instead, they have no choice but to recruit mental shortcuts—heuristics—that are assumed to make them vulnerable to committing systematic and consequential reasoning errors.

If the human mind is indeed a profoundly limited information processing machine, people need all the help they can get to surmount their deficiencies. And perhaps neuroenhancers are just what the doctored ordered. Yet a new conception of human decision-making suggests that simple heuristics are in fact indispensable and powerful mental strategies that enable people to reckon with uncertainty and complexity. This research demonstrates that there is no general trade-off between accuracy and effort. Simple heuristics can be as accurate as or more accurate than strategies requiring much more computation and information (e.g., Gigerenzer et al. 2011; Hertwig et al. 2013).

Relatedly, work on language acquisition has demonstrated that limiting "memory span" can facilitate language acquisition (Cochran et al. 1999; Elman 1993; Kersten and Earles 2001; Newport 1990; see also Plunkett et al. 1997). Memory researchers have emphasized the importance of forgetting for an adaptive memory system (Altmann and Gray 2002; Benjamin 2011), mental health (de Quervain 2008), and the accuracy of simple heuristics (Schooler and Hertwig 2005). Still other researchers have demonstrated that reliance on small samples enables surprisingly accurate inferences (e.g., Hertwig and Pleskac 2010; Vul et al. 2014), and so on.

The crucial implication of this and related research is that endowing the human mind with increased cognitive capacities, and thus boosting its ability to encode, store, retrieve, and process information, is not a silver bullet to improve performance. Not infrequently, leaner computations, less information, and the forgetting of unneeded data *enable* good or even superior performance—less is often more. This regularity is likely to hold across different environments, ancestral and modern alike. We believe that these empirical findings and theoretical considerations profoundly challenge the more-is-better premise of neuroenhancement.

11.4 **Why aren't humans smarter already?**

We believe that asking this question can provide much-needed direction in determining where neuroenhancers may be truly beneficial and where their success is likely to be compromised by trade-offs. The following points are crucial to an evidence-based approach to neuroenhancement. The prevalence of ∩-shaped performance functions (Figure 11.1) suggests that investigations of enhancers need to describe the performance functions associated with the tasks for which they are intended to produce optimal behavior; these task-specific performance functions then need to be combined with dose–response curves. Such investigations should report performance expectations relative to individual differences in baseline performance in the task. Between-subject designs that overlook such differences are almost guaranteed to over- or underestimate actual effects and invite improper generalizations of their usefulness to people of different abilities. Furthermore, the possibility of performance trade-offs between domains suggests that researchers need to cast a wide net for potential side effects until principled methods for predicting prospective side effects are developed.

Identifying cognitive side effects is crucial, because optimization over multiple constraints implies a gain–loss asymmetry. Figure 11.2 illustrates this asymmetry. Assuming that the values of a cognitive trait (and related performance scores) follow decelerating functions (i.e., gains in functionality have diminishing returns), then beyond the point of the optimal trade-off, t^*, between two traits *A* and *B*, shifting the values of trait *A* upward (through neuroenhancers) yields a gain ($\Delta T1$) on performance scores correlated with trait *A*. At the same time, however, there is a loss ($\Delta T2$) in performance of larger magnitude on trait *B*. Such an asymmetry is an evolutionary necessity for any trait that has reached an evolutionarily stable state. That is, the asymmetry of gains and losses stabilizes selective forces around an optimal trade-off (for examples related to mental disorders, see Keller and Miller 2006).

Figure 11.2 is concerned with potential declines in performance in dimensions that are tied to the dimension to be enhanced through the evolution of cognitive processes. In reality, of course, the prospect of between-domain trade-offs is much more complex. Many drugs with the potential to enhance cognition are highly addictive, and their extended use is associated with the risk of long-term health consequences (e.g., nicotine, cocaine, and amphetamines). Understanding these adverse effects—especially in the still-developing brains of children and adolescents—is central to any evaluation of the long-term viability of neuroenhancers. Indeed, if the human brain permanently adapts to the chemical imbalance produced by the continual use of neuroenhancers and does not

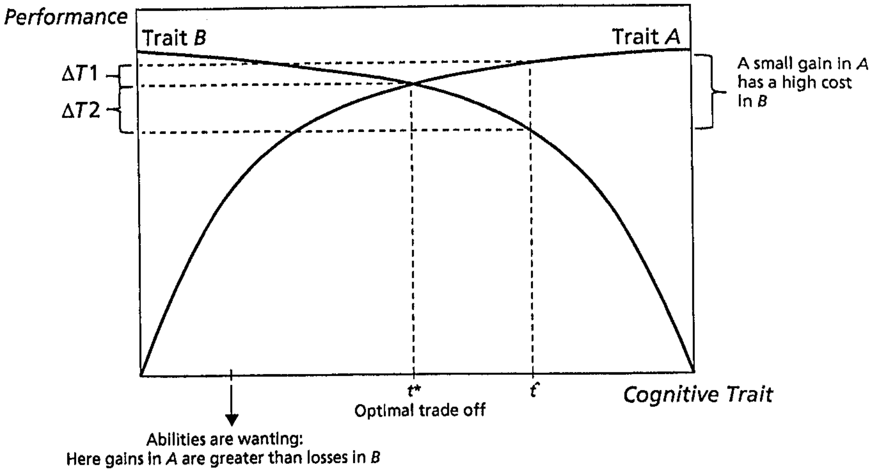

Figure 11.2 A gain–loss asymmetry. Performance scores associated with traits *A* and *B* follow decelerating functions (i.e., gains in functionality have diminishing returns); t^* represents the point of the optimal trade-off between both traits. Shifting the values of trait *A* upward (through neuroenhancers) yields a performance gain ($\Delta T1$) associated with trait *A* that is smaller in magnitude than the corresponding performance loss associated with trait *B* ($\Delta T2$).

revert to its normal state when intake is stopped, then adverse effects including cognitive impairment may be persistent. Various psychoactive drugs appear to have such severe long-term effects (e.g., Berke and Hyman 2000; Whitaker 2010).

Even if there were an ethically acceptable way to investigate these potential adverse effects in healthy people, it may be some time before the effects of drugs with cumulative and delayed negative consequences are fully realized. For instance, it was only recently possible to study the long-term health effects of smoking on women born around 1940—the first generation in which many women smoked substantial numbers of cigarettes throughout their adult lives. The observed long-term health consequences include an approximately tripled all-causes death rate and at least 10 years' reduction in life expectancy relative to nonsmokers (Pirie et al. 2013).

To conclude, the current hype about neuroenhancment in media reports that tend to emphasize the benefits of neuroenhancers and overlook their potential risks (Partridge et al. 2011) endorses a simplistic view of human cognition—namely, that more of a cognitive resource, available at demand, must invariably be a good thing. Taking an evolutionary perspective, we questioned the foundations of this view. Finally, let us stress that there are numerous nonpharmacological means to enhance cognitive capabilities throughout the life span, including physical exercise, sleep, meditation, and mnemonic strategies. Several of these strategies "seem to be more efficacious compared to currently available pharmaceuticals" (Dresler et al. 2013, 529), and they come without severe adverse effects. What they do require is investment in terms of time and/or effort. There is no such thing as a free lunch.

11.5 Acknowledgments

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