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An action video game modifies visual processing

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In a recent paper, Shawn Green and Daphne Bavelier show that playing an action video game markedly improved subject performance on a range of visual skills related to detecting objects in briefly flashed displays. This is noteworthy as previous studies on perceptual learning, which have commonly focused on well-controlled and rather abstract tasks, found little transfer of learning to novel stimuli, let alone to different tasks. The data suggest that video game playing modifies visual processing on different levels: some effects are compatible with increased attentional resources, whereas others point to changes in preattentive processing.

Will hours of playing 'Where's Waldo?' make striped sweaters jump out at you on your next trip to the department store? Would it help a baggage screener to better pick out suspicious objects from cluttered suitcases? To what extent training on one visual task transfers to other tasks is the key question in perceptual learning. In fact, although a host of experiments have shown that subjects improve with practice on a number of tasks, these same experiments often find that subtle changes of the experimental paradigm between training and testing – such as changing the shape, location or orientation of the stimuli – can have a profound effect on performance [1] (but see Ref. [2]). Such extreme specificity of learning is not of much use in the real world, where generalization and transfer from the training examples to novel scenarios, or even to different tasks, are key. In an elegantly simple and surprising paper, Green and Bavelier [3] now have provided evidence that habitual video game players (VGP) exhibit superior performance relative to non video game players (NVGP) on a set of benchmark visual tasks that tested the ability to process cluttered visual scenes and rapid stimulus sequences – skills likely to be trained by action games, which commonly require players to identify and track opponents quickly in cluttered displays and to switch rapidly between different targets. Importantly, Green and Bavelier demonstrated that this advantage is not a result of self-selection (i.e. not because subjects with superior visual abilities tend to prefer playing video games). Subjects with little or no video gaming experience showed significant improvement on the benchmark tasks after playing just ten hours of a first-person-shooter video game, *Medal of Honor*.

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Improved object detection in clutter

What differences between NVGPs and VGPs did Green and Bavelier find, and how can those differences be interpreted? In one task, subjects had to detect a briefly flashed and masked target object (a triangle in a circle) along one of eight radial spokes made up of distractor objects (squares) emanating from the fixation point. Subjects had to report the spoke the target stimulus appeared on. VGPs showed large performance advantages over NVGPs across all distances from the fixation point that were tested (up to 30° eccentricity). Green and Bavelier interpret this difference as an enhanced allocation of spatial attention over the visual field. Previously, Ball *et al.* [4], using the same task, argued for a central role of preattentive mechanisms because target detection was found to be independent of the number of distractors, suggesting a parallel process. Interestingly, comparing subject performance with and without distractors, Ball *et al.* also found that introducing distractors decreased the diameter of the central area over which the target could be reliably detected. This is compatible with observations by Green and Bavelier in another target detection task, in which both VGPs and NVGPs appeared to process probe objects in the periphery better when there were few simultaneously presented distractors (low clutter) than when there were many (high clutter). This effect might be related to recent physiological data regarding the behavior of neurons in monkey inferotemporal cortex (IT), a brain area crucial for object recognition in the primate [5]. Neurons in IT have big receptive fields and show tuning to complex stimuli such as hands or faces. A recent study [6] showed that, in the presence of simultaneously presented clutter objects, receptive fields of IT neurons appear to shrink around an object presented at fixation. This provides a possible mechanism to increase robustness of object recognition in cluttered scenes by decreasing the region of the visual field in which distractors can interfere with the representation of an object at fixation (introducing a second object into the receptive field of an IT neuron commonly interferes with the response to the first stimulus [7]). It is interesting to note that the physiological effect also occurred if the central object was not the target for action (i.e. presumably was not attended). Although this physiological mechanism could underlie the effect of clutter on object processing in the periphery [3], it cannot explain the additional observation that VGPs in the high-clutter case showed a superior ability relative to NVGPs to process probe objects presented close to the fixation point (D. Bavelier, personal communication), which would require that the IT neurons of VGPs are also less susceptible to interference caused by multiple objects within their receptive fields. Clearly, a better understanding of how the visual system performs object recognition in cluttered scenes is needed to link these behavioral effects to underlying physiological mechanisms.

Higher ‘subitizing’ capacity

Green and Bavelier further tested their subjects on an enumeration task, in which subjects viewed a flashed display containing a varying number of squares and then had to state how many items the display contained. What is commonly found is that subjects can reliably and quickly enumerate up to around four items [8] but that performance drops off precipitously for five and more items. The former process is called ‘subitizing’ and the latter is called ‘counting’. Green and Bavelier found that VGPs were able to subitize more items than NVGPs (with averages of 4.9 and 3.3 items, respectively), and they interpreted this result as another sign of an increased attentional capacity of VGPs. By contrast, current theories posit that subitizing is a preattentional process (e.g. evidenced by the fact that subjects were able to subitize whenever attention was not required to identify the targets to be enumerated [9]) and would explain the advantage of VGPs with an ability to individuate preattentively a greater number of objects than NVGPs. A preattentive account of subitizing is also supported by recent positron emission tomography (PET) studies [10] that found subitizing activated foci in the occipital extrastriate cortex (consistent with a preattentive visual process), whereas counting involved a greater network of brain regions, including some implicated in spatial attention.

Improved ability to switch between targets

Finally, Green and Bavelier tested subjects on a variant of an ‘attentional blink’ task [11], in which subjects had first to detect a target (a white letter in a stream of black letters, briefly flashed individually on a screen), and then to detect whether another target (an ‘X’) appeared in the following displays. Normal subjects show an impairment in X-detection performance for short lags between the first (black letter) and second (X) targets – the attentional blink — that slowly disappears with an increasing number of intervening items between the two targets. VGPs showed the same qualitative effect, but a significantly lesser impairment than NVGPs that also disappeared more quickly, suggesting that VGPs showed less interference between the two tasks than NVGPs did. Such interference might be due to an interaction of target-related top-down modulations and bottom-up input in visual processing. For instance, recent physiology experiments [12,13] have found that neuronal activation in area V4 (an intermediate visual area providing input to IT) can be modulated by a target cue presented elsewhere in the visual field, and that there is a 150–300 ms lag between a change of the target cue and a corresponding change of V4 neuron modulation. Another set of experiments [14,15] has shown that neurons in V4 and IT can show response modulations 150–180 ms after stimulus onset, depending on whether or not the stimulus in the receptive field of a neuron is a target. If such target-dependent activity modulations are also triggered by the detection of the first target in the attentional blink paradigm, they might contribute to the observed impairment in detection of secondary targets that follows within a certain interval, because the top-down modulations would not be compatible with the changed bottom-up input. The observed advantage of VGPs would then imply a shortened time course of these modulations as a result of training, suggesting interesting predictions for physiological experiments.

The road ahead

The neural mechanisms underlying even simple visual tasks are still poorly understood. Even less progress has been made on understanding how these mechanisms are modified by visual experience. For both issues, the intriguing paper by Green and Bavelier provides ample food for thought, and raises a host of new questions.

On the experimental side, a key challenge is to get a better understanding of the necessary and sufficient conditions to obtain the different observed training effects, which would help to understand which effects are linked through common neural mechanisms. For instance, is it possible to get an improvement in just one task – for example, in subitizing – without a concomitant improvement in the other tasks? In their paper, Green and Bavelier demonstrated that training consisting of playing the video game Tetris, which arguably trains a skill set different from that for first-person-shooter games (players have to rotate an oddly shaped block dropping towards the bottom of the screen so that it best fits onto the surface created by previously dropped game blocks), did not induce improvements on the test tasks [3].

On the theoretical side, a striking feature of their results is that video game playing improved performance in very different test tasks and generalized to novel stimuli and locations. It appears difficult to explain the wide range of training effects with a single mechanism, even one as unspecific as an increase in attentional capacity. Just as playing the increasingly complex and realistic video games of today draws on a varied set of skills, it is likely that stimulus- and task-driven plasticity at multiple levels of visual processing contribute to the observed advantages of VGPs over NVGPs [16]. Clearly, a better understanding of the computational mechanisms involved in attention and object recognition in the cortex is needed. Tasks such as those used by Green and Bavelier involve substantial interactions between attention and object recognition, and it will be necessary to extend present models [17,18] to incorporate these interactions.

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The cystine–glutamate transporter in the accumbens: a novel role in cocaine relapse

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Baker *et al.* have recently studied the potential role of cocaine-induced alterations in accumbens cystine–glutamate transporter activity (which controls basal extracellular glutamate levels) during cocaine-induced relapse to drug seeking in rats. Their data provide new evidence that neuroadaptations induced by repeated exposure to cocaine and subsequent withdrawal can play a causal role in drug relapse. These data also suggest the cystine–glutamate transporter as a novel target for medication that could prevent cocaine relapse.

The main hypothesis that guides current neurobiological research on cocaine relapse is that chronic drug exposure causes long-lasting neuroadaptations in the brain that underlie relapse vulnerability during abstinence periods [1,2]. However, despite numerous reports on cocaine-induced neuroadaptations [2,3], a causal relationship between specific neuroadaptations and drug relapse has not been established [4,5]. Previous research by Kalivas' group indicates that one form of cocaine-induced neuroadaptation is the decrease in basal levels of extracellular glutamate in the nucleus accumbens (NAc) after several weeks of withdrawal from cocaine [6,7]. These basal glutamate levels are primarily controlled by a non-synaptic cystine–glutamate transporter that exchanges extracellular cystine for intracellular glutamate, with a minimal contribution of synaptic glutamate release [8]. Using *in vivo* microdialysis, Kalivas' group also found that the decrease in extracellular basal levels of NAc glutamate after withdrawal from cocaine self-administration is associated with increased synaptic glutamate release induced by acute cocaine injections [7]. Furthermore, Kalivas and colleagues [7,9] and Park *et al.* [10] provided evidence that the glutamatergic projection from the prefrontal cortex to the NAc is involved in cocaine-induced reinstatement of drug seeking and that this reinstatement depends on activation of synaptic AMPA receptors in the NAc.

Based on these previous findings, Baker *et al.* [11] determined whether diminished activity of the cystine–glutamate transporter after withdrawal from cocaine underlies the reduction in basal extracellular NAc glutamate levels, and whether pharmacological restoration of the transporter activity would attenuate cocaine-induced reinstatement of extinguished drug seeking. The authors used a reinstatement procedure (a preclinical model of drug relapse) in which the effects of drug or non-drug stimuli on reinstatement of drug seeking are determined following drug self-administration training and subsequent extinction of the drug-reinforced behavior [12].

Baker *et al.* [11] found that a reduction in extracellular glutamate levels in the NAc was accompanied by a reduced affinity of the cystine–glutamate transporter for cystine. These effects occurred three weeks after withdrawal from cocaine. Surprisingly, the reduction in extracellular glutamate levels was anatomically specific: it was not found in

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