Lie detection and language comprehension

People who can't understand words are better at picking up lies about emotions.

People are usually no better than chance at detecting lies from a liar's demeanour[1,2], even when clues to deceit are evident from facial expression and tone of voice[3]. We suspected that people who are unable to understand words (aphasics) may be better at spotting liars, so we tested their performance as lie detectors. We found that aphasics were significantly better at detecting lies about emotion than people with no language impairment, suggesting that loss of language skills may be associated with a superior ability to detect the truth.

We studied the lie-catching abilities of ten patients who could understand individual words but who suffered severe deficits in comprehending spoken sentences after damage to the left cerebral hemisphere (LH). Their performance was compared with that of ten patients with damage to the right cerebral hemisphere (RH), ten healthy controls (C) and 48 undergraduates from the Massachusetts Institute of Technology (UC). Subjects watched a videotape in which each of ten people was shown twice consecutively: once attempting to conceal powerful negative emotions and once honestly revealing positive emotions. The sequence of the two interviews was random. Behavioural measurement showed that the interviews differed in subtle facial expressions and in pitch changes in the voice[4].

Aphasics were significantly more accurate than controls at detecting lies. The mean of the LH group (0.61; s.d. = 0.10) was higher than that of the RH, C or UC groups (0.44, 0.47 and 0.46 respectively with standard deviations of 0.11, 0.16 and 0.16). An analysis of variance of the three matched groups (LH, RH and C) found a significant difference among groups ($F_{2,26} = 4.33$, $P < 0.03$). A planned contrast analysis comparing the LH group against the others was statistically significant ($F_{1,26} = 12.95$, $P < 0.002$) and the residual variance in the main effect was not significant; *t*-tests comparing the means of all four groups against the value of 5 (the value obtained by chance) revealed that only the LH group scored better than chance ($F = 9.00$, $P < 0.02$).

We then compared the performance of all groups on items where the clues were in facial expression (3 items), in pitch changes in the voice (1 item) or in the face and voice (6 items). LH patients do better when clues are in facial expression but not when the cues are from the voice alone (Table 1).

Our results support the untested claim that aphasic patients are unusually sensitive to deceitful behaviour[5,6]. Perhaps damage to the circuitry underlying language comprehension results in the growth of compensatory skills in recognizing non-verbal behaviour. All but one of our aphasic patients were tested more than one year post-injury (the one who was tested within a year scored no better than chance). Although we cannot distinguish whether our patients were better lie detectors or simply better at detecting subtle cues to emotion, aphasics' abilities to recognize non-subtle facial expressions have, to our knowledge, never before been shown to be superior to those of controls[7,8]. The superiority of aphasics to normal persons in any task is a rarity.

Table 1 Success in interpreting lying cues

Group	Vocal pitch cues only	Facial expression cues only	Facial and vocal cues
LH	0.30	0.73	0.60
RH	0.20	0.50	0.45
C	0.20	0.57	0.47
UC	0.32	0.50	0.47

Values represent proportion correctly identifying liars. LH, left-hemisphere-damaged aphasics, mean age 58.4 years, patients at the Massachusetts General Hospital who gave informed consent. Their diagnoses, based on neurological examinations and MRI, were left middle cerebral artery infarct (nine patients) and subarachnoid haemorrhage (one subject). Neuropsychological testing revealed at least low average intellectual and perceptual abilities. Subjects achieved 95% correct (87.5–100% range) on a word-to-picture matching task and 89% correct on a lexical decision task (78–94% range)[9], indicating recognition of single words. However, they performed at near-chance levels on a sentence-to-picture matching task, with an average accuracy of 58% (53–69% range)[10], suggesting severely compromised comprehension of sentences. RH, right-hemisphere-damaged patients, mean age 59.6 years. C, matched controls, mean age 60.2 years. Both RH and C groups had equal numbers of men and women, were matched with the LH patients for education and IQ scores, were patients at the Massachusetts General Hospital, and had given informed consent. UC, undergraduate controls.

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Growth factors

Formation of endothelial cell networks

The growth factor VEGF (vascular endothelial growth factor) promotes the formation of blood vessels in a process known as angiogenesis by inducing the proliferation and migration of endothelial cells[1]. We show here that VEGF has another proangiogenic function — it can stimulate the elongation, network formation and branching of non-proliferating endothelial cells in culture that are deprived of oxygen and nutrients. As endothelial cells in tumours are exposed to chronic or intermittent hypoxic conditions[2,3], we propose that autocrine endothelial VEGF contributes to the formation of blood vessels in a tumour and promotes its survival.

Human umbilical-vein endothelial cells (HUVECs) and bovine adrenal cortex capillary endothelial cells were cultured in a sandwich system[4], in which the medium can only reach the cells from the edges of the culture (Fig. 1a). The combined processes of diffusion, consumption of oxygen and nutrients, and production of metabolites establish microenvironmental gradients across the width of the culture, like those that occur in tumours *in vivo*[4–6].

These gradients cause the cells to change shape and to reorganize themselves into networks (Fig. 1b,c). HUVECs at a distance of 0–2 mm from the edge of the sandwich cultures, where nutrients and oxygen are plentiful, retain their homogeneous, intact monolayer configuration (Fig. 1b). The monolayer morphology of HUVECs further in (3–5 mm from the edge) is disrupted and some endothelial networks are evident (data not shown). At the most hypoxic interior of the sandwich, 10–12 mm from the edge, these networks are fully formed (Fig. 1c). Control cultures, which had no top slide

and thus no gradients, kept their homogeneous monolayer configuration. Expression of VEGF protein increased starting from the edge of the sandwich culture and peaked in the central O_2/nutrient-poor region (Fig. 1d), an effect also seen for stromal cells in sandwich culture[6].

To investigate the temporal and spatial dynamics of this process, we measured the partial pressure of oxygen (pO_2), the concentration of VEGF, and the segment and branch lengths of developing networks after 0, 1, 1.5, 3, 6, 9 and 24 hours in sandwich culture (Fig. 2, and Supplementary Information). Pronounced gradients of pO_2 were created after 1 hour's culture, with cells on the interior experiencing oxygen levels below 30 mm Hg, dropping to about 5 mm Hg after 1.5 h (Fig. 2a).

The oxygen gradient induced a gradient of VEGF expression in the opposite direction (Fig. 2b). By 1.5 h, there was only a moderate increase in VEGF expression apparent in the interior, with no evidence of endothelial networks. VEGF gradients were clearly established at 3 h, while networks were only partially formed; networks then progressed to full formation over the next 6 h under minimal pO_2 (Fig. 2c,d). Networks and pO_2 gradients were produced even in the absence of glucose or serum gradients (see Supplementary Information). Our results indicate that hypoxia-induced endothelial VEGF drives these cells to form into networks in the absence of other cell types or exogenous growth factors.

To determine whether network formation was directly mediated by endothelium-produced VEGF, we added an anti-VEGF neutralizing antibody (A4.6.1, Genentech; 19.3 μg ml^{-1}) to sandwich cultures before positioning the upper slide. After 9–10 h, networks were fully developed in untreated HUVEC sandwich cultures, but, despite the gradient in oxygen tension, were absent in cultures that had undergone anti-VEGF treatment (see Supplementary Information). VEGF thus appears to be necessary for the formation of endothelial networks under oxygen/nutrient-gradient conditions.

VEGF acts as a mitogen on endothelial cells[7] and as a survival-promoting factor on immature blood vessels[1,7]. We have shown that it can also promote endothelial network formation without requiring cell proliferation, by inducing the elongation and reorganization of endothelial cells. The short time required for network formation (6–7 h) would not allow significant proliferation to occur (Fig. 2). Also, cultured HUVECs grow maximally at 7.5–10% O_2 (pO_2, 57–76 mm Hg)[8], tensions that exist only at the edge of the sandwich culture, where no networks form: networks appeared instead in the most hypoxic regions where cells do not proliferate[4].

Vascular sprouting and remodelling can occur *in vivo* in both normal[9] and tumour[10] tissues without significant proliferation of endothelial cells. Because these cells in tumours are exposed to intermittent and chronic hypoxic conditions *in vivo*[2,3] and as they can upregulate VEGF under low oxy-

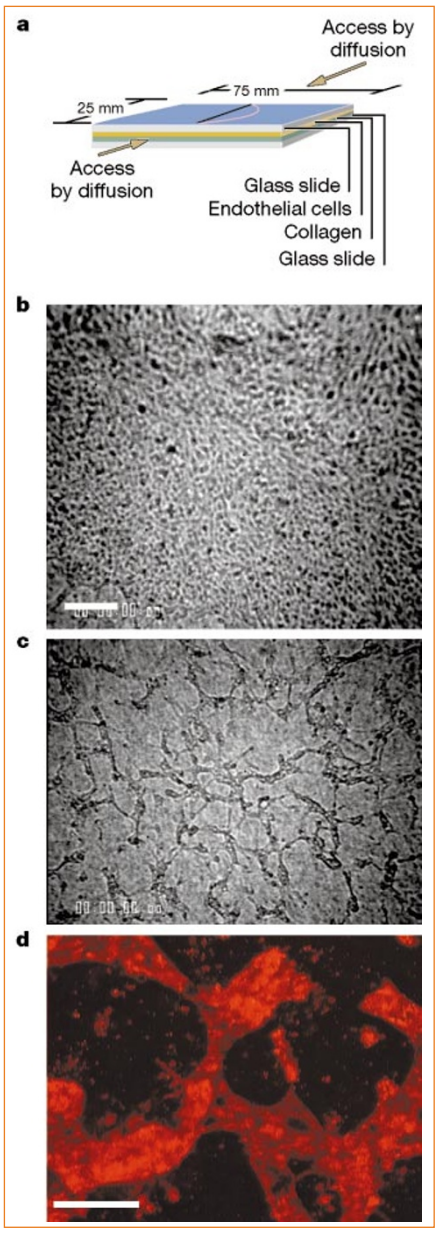

Figure 1 VEGF produced by endothelial cells (ECs) promotes network formation in the hypoxic region of tumour-mimetic sandwich cultures. **a,** Sandwich culture: ECs are plated onto a collagen-coated slide (75 × 25 mm) at the bottom; a gap of 400 ± 40 μm separates the top and bottom slides, permitting access of oxygen and nutrients only from the edges of the sandwich[4]. The black line across the culture represents the scanning line for measurements. **b,c,** HUVEC morphology as a function of position within the sandwich culture 24 hours after installing the upper slide; scale bar, 400 μm; view at 0–2 mm from the edge (**b**); 10–12 mm in from the edge (centre of the culture) (**c**). **d,** Immunohistochemical staining of VEGF in HUVECs, 11 mm from edge; scale bar, 40 μm. Cultures were fixed in cold acetone and methanol. VEGF was detected by a mouse anti-human VEGF monoclonal antibody (PharMingen) and a Cy3-conjugated secondary goat anti-mouse IgG antibody (Jackson). Similar results were obtained for BCE cultures (see Supplementary Information).

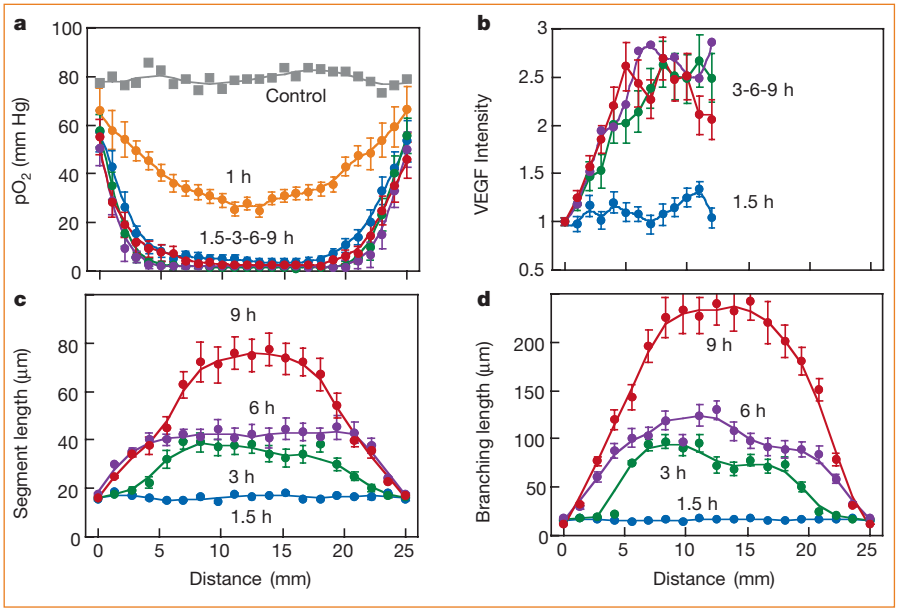

Figure 2 Measurement of spatial and temporal gradients of pO_2 and VEGF, and segment and branch lengths across the width of HUVEC sandwich cultures. Profiles are shown for pO_2 (**a**); intensity of VEGF staining (**b**); segment length (**c**); and branching length at 1 h (orange circles) (**d**), 1.5 h (blue), 3 h (green), 6 h (purple) and 9 h (red) after adding the upper slide; controls having no upper slide (grey squares); mean ± s.d. is shown ($n = 3$). The sandwich construct was transparent[4], permitting the measurement of pO_2, VEGF expression and the degree of endothelial reorganization across the culture. Oxygen gradients were measured by using a high-resolution phosphorescence quenching microscopy technique[2,13]. VEGF was detected by immunohistochemistry (Fig. 1) and mapped spatially by densitometry of digitized fluorescence images. VEGF profiles were normalized for the number of ECs, as estimated by CD31 staining (mouse anti-human CD31 monoclonal antibody; PharMingen). Endothelial network formation was assessed as a function of oxygen tension by simultaneously quantifying cell elongation and cell branching by transillumination and digital image analysis. A network segment was defined as a 'straight' line with no significant angular deviation (< 8°). The cumulative branching length was the sum total of locally connected segments.

gen tensions *in vitro*[11,12], we propose that the hypoxia-driven autocrine stimulation of endothelial cells by VEGF in solid tumours helps promote the formation and reorganization of their vascular network. Other molecules present in the tissue microenvironment, such as nitric oxide and carbon monoxide[12], may also affect endothelial VEGF production and angiogenesis *in vivo*.

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Supplementary information is available on *Nature*'s World-Wide Web site (http://www.nature.com) or as paper copy from the London editorial office of *Nature*.

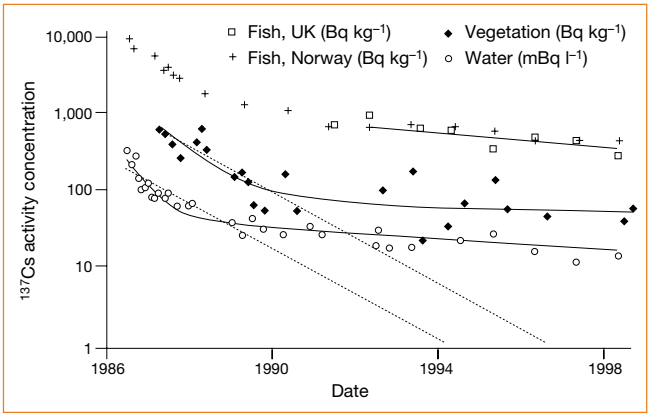

Figure 1 Long-term changes in ^{137}Cs in brown trout in Norway (from ref. 1), and in perch, terrestrial vegetation and water in Cumbria, UK. The decline in ^{137}Cs in immature fish, water and vegetation during the first five years has an effective ecological half-life (T_{eff}) of 1–4 years[1,4] as a result of 'fixation'. Dotted lines indicate the hypothetical continuation of irreversible fixation. Fits of the two-exponential model to our data, indicating the reversibility of 'fixation', are shown as solid lines. Long-term declines in all three Cumbrian systems are similar (T_{eff} range of 6–30 years) and are in quantitative agreement with results from the Norwegian fish study[1].

Pollution

Chernobyl's legacy in food and water

Radiocaesium (^{137}Cs) from the 1986 Chernobyl accident has persisted in freshwater fish in a Scandinavian lake for much longer than was expected[1]. On the basis of new data generalizing this observation, we propose that the continuing mobility of ^{137}Cs in the environment is due to the so-called 'fixation' process of radiocaesium in the soil tending towards a reversible steady state. Our results enable the contamination of foodstuffs by Chernobyl fallout to be predicted over the coming decades. Restrictions in the United Kingdom, for example, may need to be retained for a further 10–15 years — more than 100 times longer than originally estimated.

We have measured ^{137}Cs activity concentrations (Q_t) in terrestrial vegetation (seven sites, including data from ref. 2), lake water (dissolved phase, two lakes) and mature fish (three species) in Cumbria, UK, over the same period as the Norwegian study[1]. Our results for vegetation and water contamination (examples in Fig. 1) show the same two-component exponential decline ($Q_t = Q_1 e^{-k_1 t} + Q_2 e^{-k_2 t}$) observed for immature fish[1]. The decline in ^{137}Cs in mature fish was influenced by slower biological uptake rates during the initial period after Chernobyl[1,3], so only the second component of the decline is shown for our fish data (Fig. 1).

Our results show that the effective ecological half-life (T_{eff}, the time for the ^{137}Cs concentration to reduce by 50%) in young fish, water and terrestrial vegetation has increased from 1–4 years during the first five years after Chernobyl[1,4] to 6–30 years in recent years. The common rate of decline in ^{137}Cs concentration in lake water, fish and vegetation suggests that it is controlled by the same process in all three pools. This is consistent with a controlling influence of changes in chemical availability of ^{137}Cs in soil (in these lakes, long-term ^{137}Cs in the water originates in catchment runoff[5]).

The decline in ^{137}Cs mobility and bioavailability over the first few years after fallout is believed to be controlled by slow diffusion of ^{137}Cs into the illitic clay mineral lattice[4]. This 'fixation' process controls the amount of radiocaesium in soil water and therefore its availability to terrestrial biota and for transfer to rivers and lakes[4]. Studies of ^{137}Cs in contaminated sediments[6,7], however, indicate that this process may be reversible. From the persisting mobility of radiocaesium, and particularly the increase of T_{eff} towards the physical decay rate of ^{137}Cs ($T_{1/2} = 30.2$ years), we conclude that the sorption–desorption process of radiocaesium in soils and sediments is tending towards a reversible steady state.

The continuing mobility of ^{137}Cs in the environment means that foodstuffs will remain contaminated for much longer than was first expected. In the United Kingdom, restrictions on the sale and slaughter of sheep are currently in place on 389 upland farms (with about 232,000 sheep) on which some sheep have ^{137}Cs activity concentrations above the UK limit for the entry of meat into the food-chain (1,000 Bq kg^{-1}). During our studies on three restricted farms in 1991–93 (ref. 8), the maximum ^{137}Cs level in sheep meat was 1,870 Bq kg^{-1}.

Assuming that this is typical of restricted farms within the UK and using the rates of long-term decline we have estimated, restrictions may need to remain in place on some farms for a total of 30 years after the Chernobyl accident, which is more than 100 times longer than initially expected. In some areas of the former Soviet Union, consumption of forest berries, fungi[9] and fish[10] (present ^{137}Cs content, 10–100 kBq kg^{-1}), which contribute significantly to people's radiation exposure, will need to be restricted for at least a further 50 years.

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