

4. Currie, P. J. *et al.* *Can. J. Earth Sci.* **30**, 2255–2272 (1993).
5. Ji, Q. *et al.* *Nature* **393**, 753–761 (1998).
6. Peck, J. L. *J. Morphol.* **3**, 127–136 (1889).
7. Steiner, H. *Vierteljahrs. Naturf. Gesell. Zürich* **83**, 279–300 (1938).
8. Baumel, J. J. *Adv. Anat. Embryol. Cell Biol.* **110**, 1–115 (1988).

9. Parker, W. K. *Proc. R. Soc. Lond.* **43**, 465–482 (1888).
10. Oort, van, E. D. *Tijdschr. Ned. Dierk. Vereen.* **9**, 1–144 (1904).
11. Hopp, T. & Orsen, M. in *Dinofest International Symposium, Program and Abstracts* (eds Wolberg, D. L. *et al.*) 27 (Academy of Natural Sciences, Philadelphia, 1998).

Evolutionary fitness

## Tall men have more reproductive success

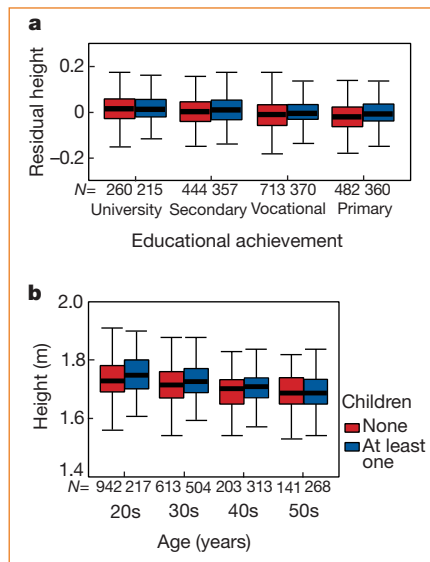
Sexual selection is a well established evolutionary process based on preferences for specific traits in one sex by members of the other sex. It is important in the evolution of morphological traits, and several sexually dimorphic traits in humans, such as facial hair and facial shape<sup>1</sup>, are assumed to be the outcome of such a process. Here we demonstrate that taller men are reproductively more successful than shorter men, indicating that there is active selection for stature in male partners by women.

There are well known academic<sup>2</sup>, social<sup>3,4</sup>, health<sup>5–9</sup> and economic<sup>10,11</sup> correlates of height, but we know of no studies that have examined its direct implications for evolutionary fitness. To examine the possible evolutionary consequences of stature, we have analysed data from the medical records for 4,419 healthy men aged 25–60 who received compulsory medical examinations between 1983 and 1989 at the Lower Silesian Medical Centre in Wrocław, Poland. Because the records were not anonymous and many bachelors admitted to having offspring, the risk of false declarations was probably small.

To avoid any confounding pathological effects, we discarded the data from men whose height was more than three standard deviations from the sample mean ( $172 \pm 6.6$  cm). Locality of residence had a significant effect on stature (analysis of variance (ANOVA):  $F_{3,4409} = 11.02$ ,  $P < 0.001$ , with city-dwellers being taller than rural men), so we selected only individuals resident in either rural villages or in cities with more than 100,000 inhabitants (the extreme sub-populations). This yielded a final sample size of 3,201.

Stature is also confounded by a secular trend (linear regression against age:  $b = -0.00157$ ,  $F_{1,3199} = 184.5$ ,  $P < 0.0001$ ), so we calculated a residual from the common regression line against age for each subject and standardized this against the overall mean for the subject's residence. Stature is also confounded by educational achievement, probably because this correlates with family wealth and status, so we controlled for education.

Figure 1a shows means and variances in stature residuals for men with and without children. When all other variables are held constant, childless men are significantly



**Figure 1** Height (mean  $\pm$  s.d. and 95% range) of men with and without children. **a**, Residual height for men with different educational experience (removing effects due to both location of residence and a secular trend over time). **b**, Absolute height for men of different age cohorts, as a function of whether or not they had any children.

shorter than those who have at least one child (ANOVA: childedness,  $F_{1,3198} = 25.5$ ,  $P < 0.001$ ; education,  $F_{1,3198} = 93.1$ ,  $P < 0.001$ ). Multiple regression with number of children as the dependent variable, with height and age as independent variables, provides quantitative confirmation of these results (one-tailed tests: city,  $r^2 = 0.136$ ,  $n = 1,826$ ; height,  $P < 0.001$ ; age,  $P < 0.001$ ; rural,  $r^2 = 0.208$ ,  $n = 1297$ ; height,  $P = 0.041$ ; age,  $P < 0.0001$ ).

Comparisons of means for individual age cohorts (Fig. 1b) reveals that men with children are significantly taller than childless men in each case (twenties,  $t_{1157} = -2.97$ ,  $P = 0.005$ ; thirties,  $t_{1115} = -3.49$ ,  $P = 0.001$ ; forties,  $t_{514} = -3.06$ ,  $P = 0.002$ ), except for men in their fifties ( $t_{409} = 0.17$ ,  $P = 0.863$ ). Because these men were born during the 1930s, they entered the marriage market shortly after the Second World War when the population sex ratio was highly skewed in favour of women and sexual selection on males would have been greatly reduced as a result: the sex ratio for adults of working age (18–64 for men, 18–60 for women) in Wrocław was 114.3 women to 100 men in the post-war decade, but fell to 104–105:100 in subsequent decades<sup>12</sup>.

These results indicate that the effect of height on reproductive output might be due to shorter men being disadvantaged in

the search for a mate. This idea is supported by the fact that bachelors were significantly shorter than married men (ANOVA with residual height as the dependent variable, childedness as the covariate, and marital status as the independent variable:  $F_{1,3198} = 7.82$ ,  $P = 0.005$ ).

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1. Perret, D. *et al.* *Nature* **394**, 884–887 (1998).
2. Teasdale, T. W., Owen, D. R. & Sørensen, T. I. A. *Human Biol.* **63**, 19–30 (1991).
3. Macintyre, S. & West, P. *Sociol. Health Illness* **13**, 149–166 (1991).
4. Bielicki, T. & Szklarska, A. *J. Biosoc. Sci.* **31**, 525–536 (1999).
5. Holl, R. W., Schroder, H. & Heinze, E. *Deutsch. Med. Wochenschr.* **116**, 928–934 (1991).
6. Barker, D. J. P. *et al.* *Ann. Hum. Biol.* **17**, 1–6 (1990).
7. Bogin, B. *Patterns of Human Growth* (Cambridge Univ. Press, 1988).
8. Herbert, P. R. *et al.* *Circulation* **88**, 1437–1443 (1993).
9. Kee, F. *et al.* *Int. J. Epidemiol.* **26**, 748–756 (1997).
10. Komlos, J. *Stature, Living Standards and Economic Development* (Univ. Chicago, 1994).
11. Schumacher, A. J. *Hum. Evol.* **11**, 697–701 (1982).
12. *Rocznik Statystyczny Miasta Wrocławia* (Miejski Urząd Statystyczny we Wrocławiu, Wrocław, 1971).

Physiology

## Eel fat stores are enough to reach the Sargasso

It has long been assumed that the European eel (*Anguilla anguilla*) migrates to the Sargasso Sea — a region of the Atlantic Ocean between the Azores and the West Indies — to spawn<sup>1–3</sup>. During the past decade, however, the number of glass eels has inexplicably dropped<sup>4</sup>, and it has been suggested that a shortage of fat stores in adults, resulting from diminished food resources for juveniles in inland waters, may prevent the starving silver eels from reaching the spawning grounds<sup>4–6</sup>. But we find that the energetic cost of the 6,000-km migration is actually quite low, with 60% of the fat store remaining available for the developing gonads.

Silver eels leaving the coasts of Europe between September and November are likely to reach the Sargasso Sea from February to June<sup>3</sup>, so the average swimming speed for a female silver eel 1 metre long is about half a body-length per second. The estimated energy required is around 30% of the total energy at the start<sup>7</sup>. The fat reserves of migrating silver eels range from

**Table 1 Energy cost of swimming of migrating silver eels**

Mean O <sub>2</sub> consumption (ml O <sub>2</sub> kg <sup>-1</sup> h <sup>-1</sup> )	Energy consumption (cal g <sup>-1</sup> h <sup>-1</sup> )	Swimming distance (km)	Energy cost of swimming (cal g <sup>-1</sup> km <sup>-1</sup> )
46.13 (± 9.90)	0.222 (± 0.048)	387.1 (± 11.27)	0.137 (± 0.026)

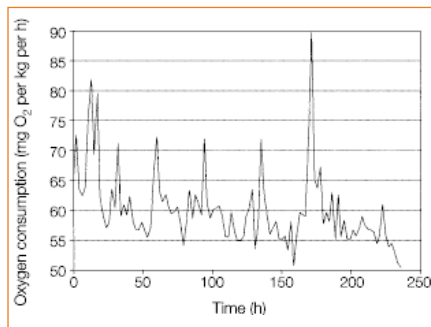
Values are mean (± s.d.) for five eels.

10 to 28% (ref. 5), which suggests that most European silver eels cannot finish the journey.

We therefore measured the energy consumption of silver eels (1 m long) that were swimming continuously at half a body-length per second for 10 days (Fig. 1). We converted the oxygen-consumption data to fat oxidation by using the oxycaloric value of fat<sup>9</sup>, the only suitable fuel. The eels' fat-consumption rates when resting and swimming were 10.11 ± 0.36 and 23.06 ± 0.41 mg fat per kg per hour, respectively.

We can use these values to calculate the energy costs for migrating eels. The fat content of silver eels ranges from 10 to 28% with a mean of 20% (ref. 5). Assuming that a 1-m adult silver eel weighing 2 kg, of which 400 g is fat, migrates 43.2 km a day (at half a body-length per second), it will take 139 days for it to reach the Sargasso Sea. During this time it will use about 154 g fat, corresponding to 38.5% of its fat stores. It has been suggested<sup>10</sup> that the energy cost is between 0.329 and 0.417 cal per g per km, some 2.4–3.0 times higher than our results of 0.137 cal per g per km (Table 1). The energy costs may actually be even lower because silver eels migrate at lower temperatures and may be using westward currents.

According to our data, about 60% of the eel's initial fat reserve can be used for gonad development at the end of the journey. Based on a mean energy content of fish eggs of 23.48 kJ per g dry weight<sup>11</sup>, a 2-kg female silver eel would be able to produce 413 g of eggs. This corresponds to a gonad-somatotrophic index of 22, which is a normal value for hormone-treated animals<sup>7</sup>.



**Figure 1** Oxygen consumption of a silver eel (1.5 kg, 90 cm long), swimming at half a body-length per second, measured continuously between 90 and 80% air saturation. Adult migrating silver eel were studied in a 127-litre swim tunnel<sup>8</sup>, with a water temperature of 14 °C and salinity of 33‰. The swim tunnel was calibrated using a laser doppler method at the Hydraulics Laboratory TU, Delft. There was a linear relation between the revolution rate of the propeller and the water velocity, which enabled us to apply a water velocity of half a body-length per second for every eel.

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- Schmidt, J. *Nature* **111**, 51–54 (1923).
- Miller, M. & McCleave, J. D. *J. Mar. Res.* **52**, 743–772 (1994).
- Fricke, H. & Kaese, R. *Naturwissenschaften* **82**, 32–36 (1995).
- Castonguay, M. *et al. Fish. Oceanogr.* **3**, 197–203 (1994).
- Svedäng, H. & Wickström, H. *J. Fish. Biol.* **50**, 475–486 (1997).
- Tesch, F. W. *The Eel. Biology and Management of Anguilloid Eel* (Chapman & Hall, London, 1977).
- Boëtius, I. & Boëtius, J. *Dana* **1**, 1–28 (1980).
- van Dijk, P. L. M. *et al. J. Fish. Biol.* **42**, 661–671 (1993).
- Elliot, J. M. & Davison, W. *Oecologia* **19**, 195–201 (1975).
- Schmidt-Nielsen, K. *Science* **177**, 222–228 (1972).
- Wootton, R. J. *Symp. Zool. Soc. Lond.* **44**, 133–159 (1979).

**Orthography**

**Children learn an untaught rule of spelling**

Children learn the rules of spelling (orthography) through teaching, and also by themselves through reading. The relative influence of these two kinds of learning is an important issue in the study of reading<sup>1,2</sup>, but it is hard to determine because children have both types of experience with most rules. Here we show that children can learn a sophisticated orthographic rule for themselves, without the help of teaching.

In English, some past-tense verbs ending in ‘d’ or ‘t’ are spelled with an ‘-ed’ ending, but others are spelled phonetically (for example, ‘told’ and ‘slept’). It takes English children several years to learn when to use ‘-ed’ to represent the past-tense morpheme and when to write them phonetically<sup>3</sup>. They may learn to do this by rote, but another possibility is that they learn an untaught rule for verb endings.

The rule is that verbs whose stems sound the same in present and past forms (such as ‘clear’ and ‘peel’) are given the ‘-ed’ spelling (‘cleared’ and ‘peeled’), and verbs whose stems sound different in the present and past (such as ‘hear’ and ‘sleep’) have phonetically spelled endings (‘heard’ and ‘slept’). This stem-based rule is not taught in English schools.

In two experiments, we asked eight- and nine-year-old children (102 children in the first experiment and 90 in the second) to write ‘pseudo-verbs’ (made-up verbs) which either had the same stem in the present and past or had different stems. If children knew the stem-based rule, they should put ‘-ed’ endings on the past tense

of pseudo-verbs that have the same stem as in the present tense more often than on those that do not.

We gave the children written passages (24 passages in the first experiment, 18 in the second) in which there was a missing word, denoted by a gap. We then read out the whole passage, including the missing word, which the child was asked to write in the gap.

In each passage, the pseudo-verb occurred three times, twice with its present-tense stem, and the third time in the past tense. The missing word, for example ‘chaild’, which the children had to write, was always the past pseudo-verb. Sometimes the stem sounded the same in the present and past tenses: ‘Harry is a chailer. At the moment he is chailing the teacher’s book. He \_\_\_ another one this morning.’ But sometimes the present and past stems sounded different: ‘Harry is a cheller. At the moment he is chelling the teacher’s book. He \_\_\_ another one this morning.’ If children follow the stem-based rule, they should spell the missing word as ‘chailed’ in the first passage and as ‘chaild’ in the second passage.

The children did use the ‘-ed’ ending to spell the past-tense morpheme more often in passages with the same stem than in those with different stems (71.92% versus 50.83 in the first experiment, and 64.67% versus 54% in the second). They also spelled the ending phonetically more often in the different-stem than in the same-stem passages (36.67% versus 17.17% in the first experiment, 34.50% versus 21.37% in the second).

Our discovery that many eight- and nine-year-old children use a morphemically based, but entirely untaught, orthographic rule has important implications for theories of spelling. The dominant theoretical approach to the study of spelling has been the dual-route model, which claims that people spell words either by converting sounds into letters, or through a lexical route in which spellings of known words are retrieved whole from memory<sup>4</sup>.

The idea of whole-word retrieval has been criticized<sup>5,6</sup> on the basis that the lexical route involves analysis of words into morphemes. Our data support this morphemic view, and indicate that morphemic structure has a radical effect on the way that children spell known and unknown words.

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