Older bull elephants control young males

Orphaned male adolescents go on killing sprees if mature males aren't around.

Musth is a state of heightened sexual and aggressive activity in male elephants[1,2]. Between 1992 and 1997, young orphaned musth male African elephants (*Loxodonta africana*) that had been introduced to Pilanesberg, South Africa, killed more than 40 white rhinoceros (*Ceratotherium simum*). The killing ceased after six older male elephants were introduced from the relatively normal Kruger Park population. The deviant behaviour of the young Pilanesberg males was rectified by the consequent reduction in musth.

Musth, during which males experience dramatic surges in circulating testosterone[3,4], is characterized by a distinct posture, swollen and secreting temporal glands, urine dribbling, and increased sexual and aggressive behaviour[2]. Males gradually enter musth as they become bigger and more experienced and better at winning encounters with other males[5]. In natural populations musth first occurs between 25 and 30 years of age[2] and its duration increases with age (for age 25–30 years, musth lasts from days to weeks; at 31–35, it lasts for several weeks; at 36–40, for 1–2 months; and after 40 years of age, 2–4 months)[2].

Young orphan elephants of less than ten years old were reintroduced to Pilanesberg in the 1980s. These were the survivors of Kruger Park culls and they matured in the absence of adult males. Males were breeding successfully by 18 years old and were entering musth from that age. Musth lasted for up to five months, an unusually long time even for males of more than twice that age[2].

In Amboseli, Kenya, young male elephants were found to be significantly less likely to be in musth if a larger musth male was present[5]. Young males also lose the physical signs of musth minutes or hours after an aggressive interaction with a higher-ranking musth male — it seems that they are forced out of musth by repeated encounters with older males[2,5]. By inference, larger, older males may delay the onset of musth in younger males.

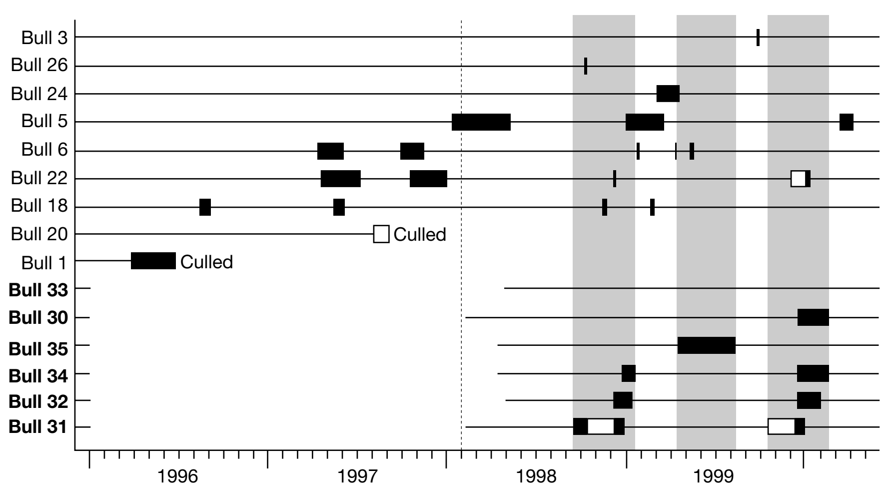

Figure 1 Observed (black bars) and probable (white bars) musth periods of elephants identified by number. Kruger Park males (bulls 30–35, bold type) were introduced to Pilanesberg (25° 15′ S, 27° 05′ E) between 6 February (vertical line) and 21 March 1998. Shaded areas indicate periods when at least one Kruger male was in musth. Only Pilanesberg males (bull numbers not in bold) that entered musth are shown. The original elephant population was brought from Kruger in 1981 (13 juvenile males, 5 juvenile females), 1983 (13 juvenile males, 11 juvenile females) and 1993 (19 males, 17 females) and from Namibia in 1982 (1 juvenile male, 1 juvenile female). The first calf was born in 1989, showing that males began breeding at about 18 years. Additional details are available from the authors.

We tested this idea by introducing six older males to Pilanesberg's population of about 85 elephants, which included 17 young males aged between 15 and 25 and independent of family groups. Musth had been recorded in six of these 17. We expected musth in the original young males to become shorter, the onset of first musth to be delayed and, with deviant behaviour being controlled by a reduction in rank, fewer rhinoceros to be killed.

Musth duration in young males declined significantly after the older Kruger Park males were introduced to Pilanesberg (Table 1 and Fig. 1; Wilcoxon paired signed ranks test: $z = -1.826$, 1-tailed $P = 0.034$). Indeed, musth was shorter in all males, and musth periods of males entering musth for the first time were also significantly reduced (Table 1; Mann–Whitney U-test: $z = -1.938$, 1-tailed $P = 0.027$) after the introduction.

The two most extensive periods of musth in the original males occurred when no Kruger Park males were in musth (Fig. 1). Bull 5, the largest original male, was only in musth when Kruger Park males were not; his second musth period was substantially shortened, his third was further reduced, and in 2000 it was delayed by two months (Table 1; Fig. 1).

Despite our small sample sizes, these results provide strong support for the idea that older males suppress musth patterns in younger males[5]. Assessment theory[6,7] predicts that selection should favour individuals who are able to assess the physical and behavioural traits of rival males and use this knowledge of the costs and benefits of fighting and the probability of winning to adjust their own behaviour.

A strategy of dropping out of musth when confronted with aggression from higher-ranking musth males increases immediate survival, and therefore long-term reproductive fitness. Some experience may be necessary for behavioural control under musth, and its gradual acquisition

Table 1 Effect of introducing older males on musth in young Pilanesberg males

Bull	Musth before introduction		Musth after introduction	
	Dates	Duration (days)	Dates	Duration (days)
1	23 Mar–27 Jun 1996	>95	Culled before introduction	
18	18 Aug–4 Sep 1996	>**16**	17–23 Nov 1998	**6**
	19 May–1 Jun 1997	>14	25 Feb 1999	1
6	14 Apr–8 Jun 1997	**55**	24–26 Jan 1999	3
	29 Sep–13 Nov 1997	46	13 Apr 1999	1
			8–19 May 1999	12–**26**
22	Apr–Jul 1997	~90	3–4 Dec 1998	2
	12 Oct 1997–6 Jan 1998	>**86**	20 Nov 1999–12 Jan 2000	53–**77**
20	Aug 1997	Unknown	Culled before introduction	
5	4 Jan–18 May 1998	**134**	6 Jan–21 Mar 1999	**76**
			12 Mar–5 Apr 2000	24
26	None		3–9 Oct 1998	6
24	None		2 Mar–24 Apr 1999	53
3	None		30 Sep 1999	1

There may have been undocumented periods of musth before April 1996. 'Greater than' sign indicates minimum periods when bulls were not seen immediately before or after the specified dates. Ranges indicate the likely interval between the first or last date the elephant was seen in musth, and the date when it was seen out of musth before or after those musth dates. Numbers in bold were used in paired analysis.

may acclimatize males physiologically and psychologically to the extremely high levels of circulating testosterone[3,4].

This translocation ended the killing of rhinoceros by elephants. Introducing higher-ranking males may help in other reserves containing Kruger orphans where managers face similar problems. In elephant populations that have experienced massive poaching, the hunters' selection of larger males may cause similar problems once rhinoceros populations increase, and these too may be helped by importing older male elephants.

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Materials science

C_{66} fullerene encaging a scandium dimer

The geometry of carbon cages (fullerenes) is governed by the isolated-pentagon rule (IPR)[1,2], which states that the most stable fullerenes are those in which all pentagons are surrounded by five hexagons. Although this rule has been verified experimentally[3–5], it is impossible for fullerenes in the range C_{60} to C_{70} to obey it. Here we describe the production and characterization of an IPR-violating metallofullerene, $Sc_2@C_{66}$, a C_{66} fullerene encaging a scandium dimer. Our results indicate that encapsulation of the metal dimer significantly stabilizes this otherwise extremely unstable C_{66} fullerene.

We generated soot containing $Sc_2@C_{66}$ and other scandium metallofullerenes[3,4] in direct-current arc discharge of scandium/graphite composite rods under a flow of helium. $Sc_2@C_{66}$ metallofullerene was isolated using multistage high-performance liquid chromatography[6]. Starting with 800 g arc-generated soot, we were able to isolate about 2.0 mg $Sc_2@C_{66}$. The purity (99.8%) of this material was confirmed by laser-desorption time-of-flight mass spectrometry.

There are several ways in which the IPR can be violated, the most straightforward being to generate the so-called 'fused-pentagon' in which pentagons are adjacent to one another. For 66-atom carbon cages with hexagonal and pentagonal faces, there are 4,478 possible (non-IPR) structural isomers with $2\times D_3$, $1\times C_{3v}$, $18\times C_{2v}$, $112\times C_s$, $211\times C_2$ and $4{,}134\times C_1$ symmetry[7]. Considering the observed 19-lines (5×2; 14×4) in the high-resolution ^{13}C NMR spectrum of $Sc_2@C_{66}$ (Fig. 1a), only eight structural isomers of C_{66} with C_{2v} symmetry can satisfy this ^{13}C NMR pattern.

To determine the geometrical structure of the metallofullerene unambiguously, we made synchrotron X-ray powder diffraction measurements on $Sc_2@C_{66}$ at SPring-8 BL02B2. The MEM (maximum-entropy method)[5,8] three-dimensional electron-density distribution of $Sc_2@C_{66}$ obtained by the MEM/Rietveld procedure[5,8] using synchrotron X-ray diffraction is shown in Fig. 1b, together with an optimized geometry of $Sc_2@C_{66}$ based on non-local density-function B3LYP/Basis set [Sc(LanL2DZ); C(3-21G)] calculations (Fig. 1c).

The $Sc_2@C_{66}$ X-ray crystal structure is of space group $Pmn2_1$(no. 31), where a is 10.552(2) Å, b is 14.198(2) Å, c is 10.553(1) Å, and the reliability factors of the final Rietveld fitting were $R_{wp}=2.4\%$ and $R_I=13.1\%$. The final charge densities obtained by the maximum-entropy method, whose reliability factor is $R_F=5.4\%$, reveal a pair of two-fold fused pentagons on a C_{66}–C_{2v} cage that encapsulates a Sc_2 dimer; the most stable $Sc_2@C_{66}$ structure has the least number and degree of fused pentagons out of the 4,478 possible isomers (see Supplementary Information).

The ^{13}C NMR spectrum of $Sc_2@C_{66}$ shows five highly deshielding lines above 151 p.p.m. up to 167.9 p.p.m. These unusual ^{13}C NMR lines stem from those carbon atoms on the fused-pentagon area. In particular, the two lowest lines at half intensity (numbers 16 and 17 in Fig. 1a) originate from the four carbon atoms that connect two pentagonal rings.

The $Sc_2@C_{66}$ structure (Fig. 1c) contains two pairs of two-fold fused pentagons with two closely situated scandium atoms. The observed Sc–Sc distance is 2.87(9) Å, indicative of the formation of a Sc_2 dimer inside the C_{66} cage. Endohedral metallofullerenes are stabilized by intrafullerene electron transfer[3–5,9,10]; there are 40.0(2) e electrons in the area corresponding to the Sc_2 dimer calculated from the MEM charge density, a value that is very close to $(Sc_2)^{2+}$ with 40 e. The *ab initio* calculation also indicates that the Sc_2 dimer donates two electrons to the C_{66} cage, resulting in a formal electronic state of $(Sc_2)^{2+}@C_{66}^{2-}$. It is this charge-transfer interaction between the Sc_2 dimer and the fused pentagons that significantly decreases the strain energies caused by the pair of fused pentagons and thus stabilizes the fullerene cage. We conclude that the isolated-pentagon rule is not necessarily a test for stable geometry in endohedral metallofullerenes[9].

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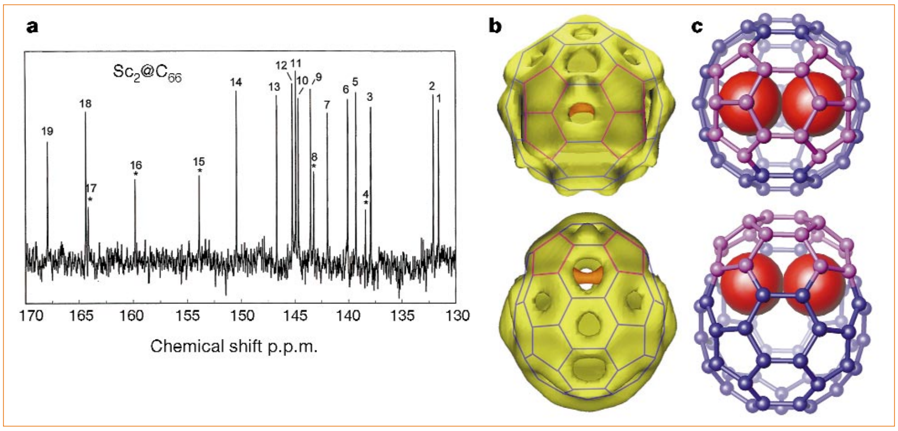

Figure 1 ^{13}C NMR and synchrotron X-ray powder diffraction structural data on $Sc_2@C_{66}$. **a,** ^{13}C NMR spectrum of $Sc_2@C_{66}$ in CS_2 solution (2.5 mg $Cr(acac)_3$, where 'acac' represents acetylacetonate, relaxant and C_6D_6 lock) after 160,000 scans at room temperature using a Varian Inova 600 spectrometer at 600 MHz. The five lines marked with an asterisk are half the intensity of the other 14 full lines (131.6, 132.1, 137.9, 138.4*, 139.3, 140.1, 142.0, 143.3*, 143.5, 144.7, 144.9, 145.2, 146.7, 150.4, 153.9*, 159.8*, 164.1*, 164.4 and 167.9 p.p.m.). **b,** X-ray structure of the IPR-violating $Sc_2@C_{66}$ fullerene, showing a top view along the C_2 axis and a side view. The equi-contour (1.4 e Å^{-3}) surface of the final maximum-entropy method electron charge density is shown; the Sc_2 dimer is in red and the two pairs of fused pentagons are evident. The X-ray powder pattern had good counting statistics and was measured in an X-ray powder experiment using synchrotron radiation and imaging-plate detectors exposed for 2 h (incident X-ray wavelength, 0.75 Å). The X-ray powder pattern of $Sc_2@C_{66}$ was obtained with a 0.02° step up to 20.3° in 2θ, which corresponds to 2.0 Å resolution in d spacing. **c,** Calculated $Sc_2@C_{66}$ structures (see text).