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Reporting Summary

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Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☐	☒	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☐	☒	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☒	☐	A description of all covariates tested
☒	☐	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☐	☒	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☒	☐	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	High-speed camera images were recorded in Photron Fastcam Viewer 4. Force data were collected using ATIDAQFT software (Demo version 2.1, ATI Industrial Automation). Robot flight data were collected using Motive software (Version 2.3, Optitrack).
Data analysis	Kinematics data were analyzed using open-source MATLAB-based DLTdv digitizing tool (DLTdv8, https://biomech.web.unc.edu/dltdv/). Other data analyses were performed using Microsoft Excel and Matlab R2021a (Mathworks). All plots were performed using OriginPro 2022 Academic (OriginLab).

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Information. Data have been deposited in the public repository at https://doi.org/10.6084/m9.figshare.25703214.

Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	N/A
Reporting on race, ethnicity, or other socially relevant groupings	N/A
Population characteristics	N/A
Recruitment	N/A
Ethics oversight	N/A

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☒ Life sciences ☐ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Life sciences study design

All studies must disclose on these points even when the disclosure is negative.

Sample size	Sample sizes were 7 for wing deployment, 8 for hindwing retraction with elytra, 10 for hindwing retraction without elytra from four beetles. No sample-size calculation was performed. Sample sizes were selected based on the limited voluntary flights of the tethered beetles, which were sufficient to show repeated wing deployment and retraction of the beetles.
Data exclusions	One data was excluded in Extended Data Fig. 1d, as the beetle opened its elytra before the cameras triggered to record.
Replication	Experiments on robots were repeated at least 3 times for each case, showing successful replication.
Randomization	Randomization was not necessary because all experimental data were analyzed.
Blinding	Blinding was not possible because all data were conducted and analyzed by one group.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☐	☒ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Animals and other research organisms

Policy information about studies involving animals; ARRIVE guidelines recommended for reporting animal research, and Sex and Gender in Research

Laboratory animals	The study did not involve laboratory animals. Ten rhinoceros beetles, Alloymyrina Dichotoma, were purchased from a local store in Korea and reared in a plastic cage at room temperature (25°C) with jelly foods before experiments. All experiments on the beetles were conducted at Konkuk University following the institutional and national guidelines for the use of laboratory animals. No specific permits were required to use the species of the rhinoceros beetles in this work as it is not on the list of protected species.
Wild animals	The study did not involve wild animals.
Reporting on sex	Both male and female beetles were used for experiments (5 males and 3 females) excluding 2 female beetles that did not show flight ability. Although flight performance of male and female beetles is similar (Phan and Park, Science, 2020), male beetles were used for tethered flight experiments. This is because male beetles with horns on their back heads can be easily fastened to a fixture without the need for adhesives, which is required for no-horn female beetles.
Field-collected samples	The study did not involve samples collected from the field.
Ethics oversight	The species of beetles used in this study is not on the list of endangered or threatened species. No specific permits were required.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Plants

Seed stocks	N/A
Novel plant genotypes	N/A
Authentication	N/A