Systematic mapping and bibliometric analysis of meta-analyses on animal cognition

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Abstract

Meta-analyses play an important role in empirically synthesising research and guiding future directions. The field of animal cognition is rapidly expanding, with both empirical and review papers increasing at a faster rate than those in the life sciences overall. However, the use of meta-analyses, their methodological rigour, and the geographic distribution of research activity remain unclear. We systematically reviewed 49 meta-analytical studies encompassing 1,824 primary studies on animal cognition. Half of the meta-analytical studies focused on the evolution and diversity of non-human animal cognition, while the other half used animals as models to understand human cognition. Most studies addressed factors affecting cognitive abilities, focusing on mammals and birds. Although many studies aimed to examine evolutionary or diversity-related questions, few analysed cognitive variation across species or tested evolutionary hypotheses, and even fewer incorporated phylogenetic relationships. While some studies investigated sex differences, many reported that they could not due to unbalanced sex ratios in the primary studies, notably a predominance of males. Both primary and meta-analytical studies often lacked adequate methodological reporting and rarely shared raw data or analysis scripts. Our bibliometric analysis showed that research is geographically concentrated, with authorship and collaboration mostly in high-income countries. To address current gaps, we recommend greater adherence to open science practices, improved regional inclusivity, and broader taxonomic and individual-level coverage. Finally, we highlight the complementary roles of meta-analyses and Big Team Science in advancing the field by improving its transparency, inclusivity, and reliability.

Keywords (1-7 terms)

Comparative psychology, Open science, Research synthesis, Reproducibility, Scientific inequality, Reporting quality, Geographic bias

1. Introduction

We constantly process vast amounts of information, both intentionally and unconsciously. Information processing is not exclusive to humans but is also critical in non-human animals (hereafter, animals). While we cannot truly know how animals experience the world, researchers strive to understand their cognitive processes, that is, how they perceive, learn, remember, and make decisions based on information from their surroundings (Shettleworth, 2001, 2010).

Animal cognition research encompasses a remarkably diverse range of studies, from topics such as learning and memory to areas that combine various cognitive aspects, including innovation (e.g., Griffin & Guez, 2014) and intelligence (e.g., Wasserman, 1993). Both empirical and review papers published on the topic of animal cognition are increasing at a faster rate than papers published in life sciences in general, see Figure 1.

Animal cognition studies often rely on small sample sizes (Farrar et al., 2020), which can limit statistical power and the ability to detect true effects. A meta-analytic approach can help overcome these limitations by synthesising findings across multiple studies. By quantitatively summarising data from multiple sources, meta-analyses can help detect consistent trends, assess heterogeneity, and highlight knowledge gaps. These advantages are particularly valuable in fields where individual studies, such as ecology and evolution, often suffer from small sample sizes and limited statistical power (Harrison, 2011). While meta-analyses have gained traction in many fields of ecology and evolution, the extent of their application in animal cognition research remains unclear. Further, as meta-analyses become more prevalent, concerns about their methodological rigour have emerged. Poorly conducted meta-analyses can lead to biased conclusions (Nakagawa et al., 2017), so ensuring their quality is crucial for producing reliable and impactful findings.

To fully understand the landscape of animal cognition research and the role and impact of meta-analyses, it is important to systematically map the breadth and focus of existing studies. This provides a comprehensive overview of research coverage, including major themes, gaps, and underexplored topics (Haddaway et al. 2016; James et al. 2016; Miake-Lye et al., 2016). Bibliometric analysis complements this by examining patterns of academic communication, such as citation counts, authorship, and co-authorship networks (Aria & Cuccurullo, 2017; Cobo et al., 2011; Qiu et al., 2014; Zupic & Čater, 2015). Together with methodological appraisals, these approaches allow us to assess the quality and scope of research syntheses and to understand how scientific knowledge is produced and shared within the field. For example, citation and co-authorship analyses reveal the influence of individual researchers and collaborative networks, which may affect research directions and outcomes (e.g., Fortunato et al. 2018; Pollo et al., 2024). Moreover, bibliometric approaches can highlight geographical trends in authorship and international collaborations, providing a comprehensive understanding of how knowledge in animal cognition is produced and shared across the global academic community.

Here, we qualitatively assess meta-analytical studies focusing on several aspects of animal cognition, including animal learning, memory, and decision-making, excluding studies focusing solely on perception (unless perception was clearly linked to the above three cognitive topics). First, we systematically map (Nakagawa et al., 2019) existing meta-analytical studies to classify their research aims and cognitive categories, and to evaluate how well they capture the diversity of species studied. In particular, we assess whether each study aims to understand animal cognition itself or uses animals as models for studying human cognition, a distinction that reflects fundamentally different research goals and perspectives. We also examine whether studies incorporated key explanatory factors such as age, sex, and species, which are essential for understanding individual- and species-level variation in cognition. Second, we evaluate the methodological rigour, transparency, and robustness of these meta-analyses by assessing, for example, whether studies reported pre-registration, shared raw data and analysis scripts, or addressed publication bias and heterogeneity. Third, we use bibliometric analysis to find research and authorship connections in animal cognition, examining both the primary studies included in meta-analyses and meta-analytical papers themselves.

2. Materials and methods

Our methods and planned analyses were registered before data extraction and analysis (Mizuno et al., 2024; https://osf.io/j5ph3). We have broadly followed the Reporting Standards for Systematic Evidence Syntheses (ROSES: Haddaway et al., 2018) for reporting our systematic map and the PRISMA Eco-Evo (O'Dea et al., 2021) for critical appraisal.

2.1. Databases and search strings

We used the following five online academic databases to find relevant meta-analytic literature on animal cognition: Scopus, Web of Science Core Collection, PubMed, PsycINFO, and Google Scholar (for non-English studies). Grey literature that is limited to PhD, Masters, and Honours theses was searched using the Belfield Academic Search Engine (BASE). We designed the Boolean-style search strings (all search strings are provided in Table S1) to identify meta-analytical studies that focused on animal cognition. Search strings written in English were checked by topic experts (LG and MS) and then modified based on their feedback. We benchmarked the search strategy by checking whether meta-analytical studies that had been collected in advance were successfully retrieved by the search strings, and we adjusted the strings accordingly. All final search strings for each database (Scopus, Web of Science Core Collection, PubMed, and PsycINFO) achieved an average retrieval accuracy of 85%. We did not set any temporal restrictions on the database searches. The search strings were translated for searches in non-English languages, appropriately modified to be compatible with Google Scholar. We limited Google Scholar searches to the top 100 results in each language, sorted by relevance. Additionally, we conducted backward and forward reference searches within the Scopus database using two key reviews (Dukas, 2004; Shettleworth, 2001). We removed duplicated bibliographic records before conducting the screening.

2.2. Screening process

We set specific inclusion and exclusion criteria for including meta-analytical studies in our systematic map, following our pre-registration (see the next section). Titles, abstracts, and keyword screening (initial screening) and full-text screening for English-language papers were conducted independently by AM, ML, PP and SN using Rayyan (https://www.rayyan.ai) using predefined criteria that aligned with the PICOS framework (Population, Intervention, Comparator, Outcome, Study type; Table S2; Foo et al., 2021). For non-English papers, screening was conducted by reviewers with language expertise: AM (Japanese), ML (Polish and Russian), PP (Portuguese and Spanish), and YY (Simplified and Traditional Chinese). AM initially screened all records retrieved from the main database searches. The articles were then divided into three equal parts (34%, 33%, 33%), and ML, PP, and SN conducted double screening. Any discrepancies in screening decisions were discussed among the reviewers and resolved by consensus. The screening process and its results are summarised in a ROSES-like flowchart (Figure 2). Two of these papers (Cauchoix et al., 2018; Lagisz et al., 2020) were authored by members of our team (ML and SN), and were reassigned to another reviewer (PP) to minimise potential bias.

2.3. Eligibility criteria

We included meta-analytical studies focusing on non-human animals, involving either unmanipulated individuals or those subject to temporary, non-invasive manipulations. Eligible studies assessed cognitive abilities such as learning, memory, or decision-making, rather than purely physiological or morphological outcomes. We excluded meta-analyses that only synthesised results from the authors' own previously published experimental studies or those conducted exclusively by their affiliated research groups.

Studies involving human participants were included if their primary focus was on non-human animals. We excluded studies that exclusively used animals bred or genetically modified for specific diseases (e.g., knockout strains for neurological disorders). However, studies using laboratory animals that were not bred for such purposes were considered eligible after discussion among the co-authors.

Our aim was to exclude studies where cognitive abilities might be confounded by chronic or irreversible biological alterations, while including those that used temporary, non-invasive interventions that more closely resembled natural variation. Studies involving temporary manipulations, such as hormone treatments or neural interventions, were included, whereas those focusing solely on permanent genetic modifications were excluded. We paid particular attention to the level and type of experimental manipulation because they affect both the interpretation and generalisability of cognitive performance.

We excluded meta-analyses that focused only on perception, as such studies typically assess intrinsic sensory or physiological processes. However, we included studies where perceptual abilities were clearly embedded within cognitive tasks, such as perceptual learning or stimulus discrimination after training.

2.4. Extracted data

AM manually extracted all data from the eligible meta-analytical studies. We applied a three-part classification to characterise each meta-analysis: (1) the cognitive topics investigated (learning, memory, decision-making, or other topics closely related to these), (2) the research aim (i.e., whether the study aimed to understand animal cognition or human cognition), and (3) the thematic focus (proximate factors, task validity, individual or species differences, evolutionary influences). We acknowledge that many of these categories are not mutually exclusive. Our classification was used as a pragmatic tool to summarise the primary emphasis of each study, rather than to impose strict boundaries between cognitive processes.

In addition to these classification variables, we also recorded detailed data on each meta-analysis, including the species or higher taxonomic groups studied, the sex and life stages of the subjects, the origin of the subjects (e.g., captive vs. wild), and the experimental context in which cognitive performance was measured (e.g., laboratory-based vs. field-based). When variables were missing in only a few studies, we retained them in the systematic map. However, variables that were frequently missing across studies were excluded to maintain consistency and ensure data reliability. For example, contextual information about the cognitive testing, such as whether the task involved foraging or predator avoidance, was rarely reported (see the **Deviations and additions to the protocol** section).

For the reporting appraisal, we used the PRISMA Eco-Evo framework to evaluate the transparency and methodological aspects of the meta-analytical studies (O'Dea et al., 2021). Key elements included study registration (and any deviations from the pre-registration) and details of the search methodology, such as sources and the repeatability of searches. We evaluated data availability, including the accessibility of raw data, metadata, and analysis scripts. We also considered how publication bias was addressed, the reporting of heterogeneity, and the acknowledgement of author contributions. We restricted our appraisal to meta-analytical studies that conducted traditional meta-analyses, defined here as those that quantitatively synthesised results using statistical models that weight effect sizes (such as random- or fixed-effects models). We did so because including both widely used and less conventional approaches would hinder a consistent evaluation of methodological quality.

For the bibliometric analysis, we downloaded the bibliometric data from Scopus for the meta-analytical studies on affiliations, including the institute and country, as well as cited and citing literature. In cases where the primary studies were explicitly identified in the meta-analyses, we also retrieved bibliometric details for these studies from Scopus.

To ensure replicability, ML independently cross-checked approximately 10% of the data (6 papers).

2.5. Data mapping

We conducted all mapping, including descriptive statistics and figures, in R version 4.4.2 (R Core Team, 2024). We used the package bibliometrix version 4.3.0 (Aria & Cuccurullo, 2017) for most of the bibliometrics analysis, while for visualisations we used packages ggplot2 version 3.5.1 (Wickham, 2011), treemap version 2.4.4 (Tennekes, 2023), and circlize version 0.4.16 (Gu et al., 2014). We also used VOSviewer (van Eck & Waltman, 2010) to illustrate author collaboration networks. All data and scripts are available at Mizuno et al. (2025).

2.6. Deviations and additions to the protocol

While we followed our registered protocol as closely as possible (Mizuno et al., 2024), some adjustments were necessary to better address our objectives and clearly present our results. These changes and additions are summarised below:

- Addition of "research aim" and "thematic focus" variables and change of "study types" and "overarching aims" variables: We revised our classification framework during the review process to better capture the aims and thematic focus of the meta-analytical study. Specifically, we introduced a two-level system: (1) "research aim" and (2) "thematic focus". These changes replaced the previous "study types" and "overarching aims", but the underlying distinctions remain reflected in the new categories. In addition, studies classified as examining factors influencing cognitive ability were further assigned to one or more of the following subcategories: proximate factors (e.g., intervention for sleep, development, hormones, environments), individual differences (e.g., age, sex), species differences, and evolutionary influences (e.g., cross-species comparisons).
- Addition of "perception" and "non-learning task" variables: These variables were added to capture whether meta-analytic studies included primary studies focused on perception and whether studies using paradigms without a training period were included as primary studies, respectively.
- Clarification on perception-related inclusion criteria: We specified the conditions under which papers addressing perception are included in the dataset.
- Exclusion of certain variables: Two variables were excluded from the systematic mapping due to inconsistent or insufficient reporting across the included meta-analytical studies. Specifically, we excluded the variables "context" (i.e., the ecological setting or function of the task) and "stimuli type" (e.g., visual, auditory, or olfactory), as these were often either not reported at all or described too vaguely to allow meaningful coding, making mapping infeasible.
- Addition of “inference” column variable: This variable was added to indicate whether we had to infer missing information about study design or subject origin based on indirect cues (e.g., the species used or the experimental context), rather than rely solely on what was explicitly reported in the meta-analytical study. For example, if the primary studies involved procedures

that clearly could only have been conducted in a laboratory (e.g., highly controlled experimental settings), we marked the study design as “laboratory” and set the “inference” value to "yes". Similarly, if the study focused exclusively on rats or mice—species that are almost always studied under laboratory conditions—we inferred the origin as “laboratory” and also marked “inference” as “yes”. In contrast, if the meta-analysis study provided some information (e.g., described the setting as “field-based testing”), but the original primary studies were not clearly described, we marked the design as “unclear” and set the “inference” value to “no”.

- We used a four-level classification (0–3) to indicate the confidence level of identifying primary studies in each meta-analysis: 0: No information available - No list of primary studies is provided, and neither the references nor the raw data offer any clues. 1: Determinable with assumptions - No list is provided, and the primary studies are not included in the reference list. However, plausible identification is possible through supplementary materials or raw data. 2: Determinable from the main text - No list is given, but the main text, figures, or tables make it possible to identify the primary studies, which are included in the reference list. 3: Explicitly provided - A clear list of primary studies is provided, or they are explicitly marked in the reference list (e.g., with asterisks).

3. Results and Discussion

We located 49 eligible meta-analytical studies (Abbott et al., 2019; Alfaro et al., 2022; Amici et al., 2019; Bánszegi et al., 2024; Bonapersona et al., 2019; Bustamante et al., 2023; Camacho-Alpízar & Guillette, 2023; Cauchoix et al., 2018; Diao et al., 2023; Dougherty & Guillette, 2018; Dunn et al., 2019; Fernandes et al., 2014; Ghirlanda & Lind, 2017; Gottlieb, 2005; Grace & McLean, 2016; Griffin, 2020; Hennefield et al., 2018; Hernandez-Lallement et al., 2022; Jonasson, 2005; Kavaliotis et al., 2023; Keeble et al., 2022; Kredlow et al., 2016; Lagisz et al., 2020; Lambert & Guillette, 2021; Leising et al., 2008; Lind et al., 2015; Macartney et al., 2022; Menting et al., 2019; Moran et al., 2021; Moreira et al., 2016; Musillo et al., 2021; Oberhofer & Noori, 2019; Ou-Yang et al., 2022; Penndorf & Aplin, 2020; Petrazzini et al., 2017; Pfaller-Sadovsky et al., 2020; Poirier et al., 2020; Riordan & Dwyer, 2019; Rocha et al., 2021; Roquet & Monfils, 2018; Schettino et al., 2024; Sep et al., 2021; Siviter et al., 2018; Song et al., 2022; Speechley et al., 2024; Szabo et al., 2019; Thornton & Lukas, 2012; Trzesniak et al., 2024; Woodley of Menie et al., 2022).

3.1. Systematic mapping

Research on animal cognition was initially motivated by efforts to understand human cognitive functions (Shettleworth, 2009). Over time, however, the field has expanded to include a growing interest in the cognitive abilities of non-human animals (referred to as animals) themselves and the evolutionary processes that shape them (Shettleworth, 2000; MacLean et al., 2012). In line with these developments, among the 49 meta-analytical studies included in this study, 24 focused on investigating cognitive abilities and their evolutionary background in animals, while 25 used animal models to study human cognition. As shown in Figure 3, the number of publications addressing both research aims has increased over time, particularly in recent years. Note that some studies were assigned to more than one cognitive category/aim/topic category.

Most meta-analytical studies addressed factors that influence cognitive ability, such as development, sex, stress, and nutrition (n = 43). Relatively few meta-analytical studies examined the presence or absence of cognitive abilities (n = 6) or evaluated the effectiveness of specific cognitive tasks (n = 8). This imbalance, namely, the predominance of meta-analyses focusing on explanatory factors over those examining ability presence or task effectiveness, may reflect methodological challenges. Factor-focused meta-analyses tend to be easier to conduct because moderator variables can often be extracted relatively easily across studies. In contrast, meta-analyses that aim to assess whether a cognitive ability is present, or to evaluate the validity of specific tasks, often face difficulties due to substantial variation in task design (e.g., differences in stimuli, reward structures, training procedures, or performance criteria), which makes comparisons less straightforward. Additionally, null results (e.g., studies that fail to show the presence of a cognitive ability) are often underreported or unpublished, further limiting the data available for synthesis. For example, studies reporting that a species failed to perform a cognitive task may be less likely to be published and, as a result, less likely to be included in meta-analyses (Farr et al., 2020, 2021; ter Riet et al., 2012). This publication bias can lead to a lack of available data in these areas, making such meta-analyses more difficult to conduct.

Regarding the cognitive topics examined, learning and memory were the most frequently studied (n = 26 and 18, respectively), while decision-making received considerably less attention (n = 4).

Achieving a more comprehensive understanding of both human and animal cognition requires an integrative perspective - one that recognises and values cognitive diversity across species and individuals. In the following sections, we highlight key aspects that should be carefully considered and transparently reported in both meta-analytical studies and primary studies on animal cognition. To illustrate their importance, we summarise how these factors were addressed and/or overlooked across the 49 meta-analytical studies we reviewed.

3.1.1. Sex

Of the 49 meta-analytical studies, 32 reported the sex of subjects, but only 22 incorporated it analytically (Figure 4a). Providing subject sex information was more common in human-oriented meta-analyses (20 out of 25) than in those focusing on animal cognition (12 out of 24). Of the 22 meta-analyses that investigated sex difference effects, 12 were human-focused and 10 were animal-focused. Eleven meta-analytical studies reported sex but did not include it in their analyses (Figure 4a). In six of these cases, the authors reported that they had intended to include sex as a moderator but were unable to do so due to male-biased sampling in the primary studies. All six were rodent meta-analyses (Macartney et al., 2022; Moreira et al., 2016; Musillo et al., 2021; Kredlow et al., 2016; Schettino et al., 2024; Song et al., 2022).

3.1.2. Life-history stage/age

Cognitive abilities can change across the lifespan (Amici et al., 2019; Gallagher & Rapp, 1997; Johnson & Wilbrecht, 2011; but see also Szabo et al., 2019), making life-history stage or age an important variable to consider. Among the 49 meta-analytical studies, 30 reported information on age or life stage, and 23 included it in their analyses (Figure 4b). Inclusion of this variable was more common in human-focused meta-analyses (14 out of 25) than in those focused on animal cognition (9 out of 24). Ten meta-analyses reported age or stage but did not analyse it (Figure 4b).

In animal experimental studies, determining the precise age of individuals can be challenging, especially with wild-caught or commercially sourced animals. Nonetheless, broad classifications (e.g., juvenile vs. adult) are generally possible. Consistent reporting and analysis of life stages would help clarify developmental effects on cognition and improve comparability across studies.

3.1.3. Species differences and phylogenetic considerations

Cognitive abilities can vary depending on individuals and species. Among the 49 meta-analytical studies retrieved, the number of species included ranged from 1 to 104 for animal-focused meta-analyses, whereas human-focused meta-analyses included between 1 and 4 species (Figure 5a). Meta-analytical studies investigating human cognition predominantly relied on rodents (24 out of 25 meta-analyses used only mice or rats) (Figure 5b). In contrast, meta-analytical studies on animal cognition and its evolutionary background included a wider range of taxa, but most still concentrated on birds and mammals (Figure 5b).

Of the 49 meta-analytical studies, 39 included data from more than one species; 19 of these focused on comparisons between rats and mice. In 37 meta-analyses, species was explicitly included as an explanatory variable or random effect in the model, and 11 meta-analyses used a phylogenetic meta-analysis model to account for phylogenetic non-independence. Failure to account for shared evolutionary ancestry may result in misleading conclusions, as similarities among species could reflect common descent rather than independent adaptations (Felsenstein, 1985; Hadfield & Nakagawa, 2010; Ives & Helmus, 2011). Incorporating phylogenetic covariance structures into meta-analyses allows researchers to statistically account for non-independence among species (Adams, 2008; Cinar et al., 2022; Nakagawa et al., 2023), thereby enabling more accurate identification of environmental or functional drivers of cognitive traits. For example, R packages such as *metafor* (Viechtbauer, 2010), *MCMCglmm* (Hadfield, 2010; Hadfield & Nakagawa, 2010), and *brms* (Bürkner, 2017) can be used.

Although interest in animal cognition is growing (Figure 1), meta-analyses that explicitly test evolutionary hypotheses remain rare. This indicates a promising yet underexplored area for future research. Several empirical studies have revealed cognitive abilities in a range of previously overlooked taxa, including insects (Loukola et al., 2017; Riveros & Gronenberg, 2009), cephalopods (Finn et al., 2009; Jozet-Alves et al., 2023), and fish (Salena et al., 2021). These findings highlight the importance of expanding taxonomic scope and incorporating phylogenetic approaches to more accurately capture the broader patterns of cognitive evolution.

Comparative work with closely related species, especially non-human primates, is also critical for researchers studying human cognition. Such research can help clarify both the evolution of human cognitive abilities and their uniqueness and continuity. However, we found only one meta-analytical study that focused specifically on primates (Griffin, 2020). Due to the large body of primary studies and the extensive availability of well-established cognitive testing paradigms, rodent models may continue to dominate empirical and meta-analytical studies on human cognition. Nonetheless, expanding meta-analytic efforts to include primates and other taxa could provide deeper insights into the evolutionary roots of human cognitive traits.

Meta-analysis is a powerful tool for synthesising findings across studies, but it is not without limitations. In studies investigating the presence or absence of cognitive abilities, for example, publication can be often possible as long as at least one individual is able to successfully complete the task (e.g., Matsuzawa, 1985; Pepperberg, 1981; Pilley & Reid, 2011; Poole et al., 2005; Weir et al., 2002). As a result, data from individuals who failed might be omitted. In operant conditioning studies, individuals who do not progress through shaping procedures, a step-by-step training method that gradually reinforces closer approximations of the target behaviour, are sometimes excluded from the analysis and may not even be mentioned in the published paper. When such studies are synthesised through meta-analysis, the resulting data may be biased toward high-performing individuals, potentially underestimating individual differences.

To address some of the limitations discussed above, Big Team Science initiatives provide a valuable avenue. Projects such as ManyBirds (https://themanybirds.com/), ManyMany (https://manymanys.github.io/), and ManyPrimates (https://manyprimates.github.io/) conduct collaborative research across multiple institutions, countries, and species, using pre-registered and standardised protocols (Lambert et al., 2022; ManyPrimates, 2019). These Big Team Science projects aim to diversify the range of species included in cognitive research by harmonising and pooling data from multiple laboratories, allowing for more robust cross-species comparisons and the investigation of comparative generalisability (Alessandroni et al., 2024, 2025). By design, these projects systematically report all experimental settings, including details on subjects, housing, and experimental conditions, as well as all outcomes, not only successes but also failures. This comprehensive reporting allows for an accurate understanding of the conditions under which cognitive abilities emerge, as well as the degree of variation at both the individual and species level.

Importantly, the research questions addressed by Big Team Science projects, such as those related to learning and memory, concern fundamental, widely shared cognitive processes that help animals adapt to changing environments and are central to animal cognition research. Big Team Science allows for rigorous hypothesis testing under highly standardised conditions, while meta-analysis can reveal broader patterns across a wide taxonomic and ecological range at relatively low cost. Rather than being competing approaches, these methods are highly complementary. Combining the strengths of both would be essential for advancing the field. Leveraging both approaches will enable a more comprehensive understanding of the diversity and evolutionary underpinnings of animal cognition.

3.1.4. Experimental setting and subject origin

Among the 49 meta-analytical studies we reviewed, 29 focused exclusively on laboratory-based studies, although 14 did not clearly describe the experimental setting and were assumed to involve laboratory-based work based on the subject (i.e., use of rats or mice). Five meta-analyses incorporated both laboratory and field data, and one included all three categories (laboratory, field, and unspecified) (Figure S1a).

Regarding subject origin, 19 meta-analytical studies were assumed to have used laboratory-reared individuals, 20 did not report this information, and a few included wild-caught or mixed populations (Figure S1b). These reporting gaps limit comparability across studies, as environmental context and prior experience can influence cognitive performance (Kelly & Lea, 2023).

With a growing number of primary studies conducted in naturalistic conditions, supported by technological advances such as remote monitoring and automated testing (Griebling et al., 2022), future meta-analyses are well-positioned to integrate findings across diverse ecological settings. Clearer reporting of both experimental setting and subject origin will enhance the interpretability of results and support more ecologically grounded comparisons.

3.2. Appraisal

We compared 40 traditional meta-analytical studies on animal cognition (i.e., meta-analytical studies using standard meta-analytic statistical methods such as effect size calculation and weighting based on sample size or variance) with the reporting criteria outlined in PRISMA-EcoEvo (O'Dea et al., 2021). The following section outlines how the meta-analytical studies we assessed align with or deviate from these guidelines. While we understand that animal cognition is sometimes more closely aligned with psychology or neuroscience than with ecology and evolution, a subfield of biology, we used PRISMA-EcoEvo as a point of reference due to the lack of comparable standards in those fields.

3.2.1. Adherence to PRISMA guidelines and research transparency

Transparency in search methodology remains a key challenge in animal cognition meta-analyses (Figure 6). Only 50% of meta-analyses reported the language of their literature search, most of which focused exclusively on English-language sources. This can introduce systematic bias, and collaboration with native speakers of other languages has been recommended as a mitigation strategy (Walpole, 2019).

Regarding search strings, only 37.5% of meta-analytical studies disclosed them fully, and 32.5% did so in a reproducible format. Furthermore, 52.5% of meta-analyses provided only exact keywords or partial examples. Compared to the PRISMA-EcoEvo survey (O'Dea et al., 2021), where only 14% of meta-analyses shared reproducible search strings, animal cognition meta-analyses appear to show modest improvement. The most commonly used database was Web of Science (n = 37), followed by Scopus (n = 20) and PubMed (n = 17); four meta-analyses relied on a single database.

Future meta-analytical studies should not only disclose search strategies but also evaluate their comprehensiveness. Insufficient sensitivity in search design may result in the omission of relevant studies and bias meta-analytic conclusions (Lagisz et al., 2025).

3.2.2. Screening and data transparency

In addition to the search methodology, we assessed how well meta-analytical studies documented their screening processes and data-sharing practices. Overall, screening was well reported: 77.5% of meta-analyses used PRISMA flowcharts or equivalent documentation, 95% clearly stated inclusion criteria, 85% reported the number of screened papers, and 62.5% provided the number of excluded full-text articles (Figure 6). These findings indicate that many meta-analytical studies in animal cognition report their screening process in a transparent manner.

However, data and code availability remain limited. Only 42.5% of meta-analytical studies provided usable datasets, 45% included metadata, and 20% explicitly reported the sources (e.g., figures or tables) from which raw data were extracted. Additionally, 32.5% of meta-analyses shared their analysis scripts. In contrast, a review of meta-analytical studies in ecology and evolution found a higher rate of data sharing (77%) but a considerably lower rate of code sharing (11%) (O'Dea et al., 2021). These findings suggest that while data availability remains a limitation in animal cognition meta-analytical studies, the field may be comparatively more transparent in terms of code accessibility.

3.2.3. Statistical considerations and methodological rigour

Most meta-analyses addressed publication bias (82.5%) and heterogeneity (85%) (Figure 6), outperforming those in the PRISMA-EcoEvo sample (65% and 52%, respectively; O'Dea et al., 2021). However, only 25% of meta-analyses accounted for phylogenetic non-independence, despite 67.5% including multiple effect sizes. This is particularly concerning for cross-species analyses.

R was the most commonly used software (62.5%), followed by programs such as Comprehensive Meta-Analysis, ProMeta, and JASP. In 0.75% of cases, the software used was not reported. Since some tools do not support appropriate handling of non-independence, careful software selection is critical. Quality assessment of primary studies was performed in 35% of the meta-analytical studies. Pre-registration was reported in 22.5%, and 55.6% of those studies documented deviations from their original plans, suggesting a growing awareness of pre-registration as a means to reduce bias and enhance transparency (Hardwicke & Wagenmakers, 2023).

3.2.4. Authorship transparency

Although not addressed in PRISMA-EcoEvo, authorship transparency is increasingly recognised as a key component of research integrity (Allen et al., 2019; Brand et al., 2015; Holcombe et al., 2020). The CRediT taxonomy (Contributor Roles Taxonomy, Brand et al., 2015) has been proposed, allowing for a rough attribution of individual roles within research projects (McNutt et al., 2018). Only a few meta-analyses used the CRediT to report individual contributions, and nearly half did not provide author contribution statements at all (Figure 6). While journal formatting requirements may influence this trend, encouraging the use of standardised authorship reporting frameworks can help ensure accountability and appropriate credit for scientific work (Logan et al., 2017; Sauermann & Haeussler, 2017).

3.3. Bibliometrics

Among the 49 meta-analytical studies, most (n = 35) clearly provided bibliometric information (e.g., author name, title, publication year, journal name) for the included primary studies (n = 1,824 total), such as lists or references. However, even among these 35 meta-analyses, eight were missing some bibliometric details for certain primary studies. Moreover, 14 meta-analyses either did not provide any bibliometric information for the included primary studies or did not explicitly identify them (e.g., although references were included in the reference list due to citations within the text, it was unclear whether these were the primary studies used in the meta-analysis). This lack of transparency makes it difficult to assess the reproducibility and comprehensiveness and undermines the reliability of meta-analyses.

The journal categories in which the 49 meta-analytical studies were published reveal that most meta-analyses fall within the fields of biology or psychology (Figure 7). Twenty-three meta-analyses, however, appeared in neuroscience journals, indicating conceptual and methodological overlap among the three disciplines. This suggests that research investigating the neural and behavioural foundations of cognition often bridges biological and psychological perspectives through neuroscience-based approaches.

The US (United States) is the leading country in publishing meta-analytical studies on animal cognition, with seven first authors affiliated with US institutions (Figures 8a and 9a). The UK (United Kingdom), Australia, the Netherlands, and Germany follow the US. The UK is the most proactive in international collaboration, followed by the US, Sweden, Germany, Australia, and Canada. This suggests that while the Netherlands has been productive in publishing meta-analytical studies on animal cognition, collaboration has largely remained within the country. On the other hand, despite not being as prolific in meta-analytical studies, Sweden is frequently involved in international collaborations (Figure 9a). The US is also the leading country in primary studies (included in meta-analyses), followed by the UK, Canada, China, Germany, and Japan. The US alone accounts for one-third of the primary studies (Figure 8). In terms of international collaborations in primary studies, the US is again the most active, followed by the UK, Germany, Canada, and China (Figure 9b).

Most authors in both primary and meta-analytical studies are affiliated with institutions in developed countries, with this trend being particularly strong in the latter case (Figure 8). Notably, we did not find any meta-analyses authored by researchers from Africa, Southeast Asia, or the Middle East. However, some primary studies included in meta-analyses did originate from the aforementioned regions. This may be due to the fact that nearly half of the primary studies focused on research involving rodents (890 primary studies). Rodents are widely used in laboratory-based research and supported by well-established protocols and infrastructure, which may contribute to their prevalence across diverse research settings, including some in low- and middle-income countries. However, we did not find active international research collaborations with low- and middle-income countries as seen in high-income countries (Figure 9).

These patterns reflect broad inequalities in global scientific research. The disparity is likely driven by factors such as limited research funding, restricted access to academic journals, and the dominance of English as the primary language of scientific publishing. Writing in English poses a significant challenge for non-native researchers, requiring substantial time and financial resources (Amano et al., 2023), and their manuscripts may be rejected due to language barriers or fail to effectively convey their significance to editors and reviewers (Rezaeian, 2015). Furthermore, researchers from developing countries face additional obstacles to participating in international collaborations, not only due to financial and language barriers but also because of national, racial, and ethnic biases (Matthews et al., 2020). To address these disparities, a comprehensive approach is needed, including strengthening international research networks (Salager-Meyer, 2008), ensuring fair and constructive peer-review processes (Lund, 2022; Skopec et al., 2020), supporting English writing assistance and multilingual dissemination of scientific findings (Rezaeian, 2015; Nakagawa & Lagisz, 2024), and more equitable research funding opportunities (Salager-Meyer, 2008; Valdez et al., 2024).

In this context of addressing global scientific disparities, one particularly promising development has been the emergence of large-scale, collaborative Big Team Science projects. Some of these initiatives have explicitly incorporated principles of Equity, Diversity, and Inclusion (EDI) into their frameworks. Such projects demonstrate strong commitments to creating open, welcoming, and harassment-free environments for all participants, regardless of their nationality, ethnicity, socioeconomic background, language, or other personal attributes. While advancing EDI may not be their primary aim, it is crucial that these commitments go beyond rhetoric. Concrete actions, such as lowering participation barriers and providing support for underrepresented researchers, are necessary for real progress toward a more equitable scientific community, and may help to address some of the disparities highlighted above.

Although it remains to be seen whether these efforts to foster inclusion and reduce participation barriers will lead to greater participation and collaboration from researchers in low- and middle-income countries, the emergence of such large-scale, collaborative, and inclusive initiatives represents a promising step toward a more equitable and diverse global research community. At the same time, these large-scale collaborative efforts, through their EDI initiatives, can also broaden the taxonomic scope of research, which may ultimately lead to a deeper understanding of the evolution of animal cognition itself.

While large-scale collaborative initiatives are encouraging, it is also important to consider the current landscape of research impact and community structure. Our bibliometric analysis revealed that the majority of primary studies in animal cognition received only a single citation within 49 meta-analytical studies (1,727 out of 1,824 papers). This pattern suggests that individual studies may have limited impact, potentially due to the fragmented nature of the field or the diversity of study species and methodologies. Further, we found that influential researchers in animal cognition tend to be concentrated in specific institutions and countries. For example, researchers affiliated with the University of St Andrews and the University of Cambridge in the UK, as well as Rutgers University and the Medical University of South Carolina in the US, form identifiable clusters (Figure S2). This concentration may be explained by established research traditions, well-developed infrastructures, plentiful institutional funding, and strong mentorship networks. However, such geographic clustering could also potentially introduce biases in research focus and theoretical perspectives.

4. Recommendations and Conclusion

In this study, we reviewed 49 meta-analytical studies on animal cognition using systematic mapping, research appraisals, and bibliometric analysis to provide an overview of the current state of research in this field. We identified three major, interconnected challenges and gaps: (1) inadequate methodological transparency and reporting, (2) limited taxonomic and phylogenetic coverage, and (3) geographic and institutional concentration of research efforts. Below, we propose potential solutions and recommendations for future research (Figure 10).

First, insufficient reporting of experimental details, raw data, and analysis code undermines the reliability and reproducibility of both empirical and meta-analytical studies. Meta-analyses are often hindered by insufficient reporting in empirical studies, such as missing information on the life stage or origin of subjects (Macartney et al., 2022; Moreira et al., 2016; Musillo et al., 2021; Kredlow et al., 2016; Schettino et al., 2024; Song et al., 2022). Moreover, many meta-analytical studies themselves fail to share raw data or analysis scripts, which further reduces transparency and reproducibility.

Standardised reporting guidelines and open science practices, including preregistration and sharing of data and code, are important for improving scientific rigour and credibility. In empirical studies, guidelines such as ARRIVE (Kilkenny et al., 2010; Percie du Sert et al., 2020), CRIME-Q (Andersen et al., 2024), GSPC (Hooijmans et al., 2010, 2011), and NIH standards (Landis et al., 2012) are intended to ensure that methodological details are properly reported. Nevertheless, adherence to these guidelines remains inconsistent (Leung et al., 2018; Song et al., 2024), highlighting the need for journals to more rigorously assess compliance with reporting standards (Song et al., 2024). For meta-analyses, frameworks like PRISMA/PRISMA2020 (Moher et al., 2009; O'Dea et al., 2021; Page et al., 2021), ROSES (Haddaway et al., 2018), and Campbell et al. (2020) help reduce missing or incomplete reporting of critical information, and SYRCLE’s RoB tool (Hooijmans et al., 2014) can evaluate primary study quality. Pre-registration (e.g., PROSPERO: Booth et al., 2012; OSF Registries) and PREPARE guidelines (Smith et al., 2018) can further enhance transparency and reproducibility (Hardwicke & Wagenmakers, 2023; Simmons et al., 2021). Registered Reports, with peer review before data collection, also enhance the quality and reliability of research (Chambers & Tzavella, 2022; Soderberg et al., 2021).

Second, despite findings of a variety of cognitive abilities in non-mammal or -bird taxa (e.g., Bshary & Brown, 2014; Lucon-Xiccato et al., 2024; Matsubara et al., 2017; Perry et al., 2017; Schnell, Amodio, et al., 2021; Schnell & Clayton, 2019, 2021), most meta-analytical studies still focus on mammals and birds. Expanding taxonomic coverage, by including currently underrepresented groups, would be necessary for understanding cognitive evolution. Careful consideration of sources of individual variation, such as sex or developmental stage, is also needed. Notably, few meta-analyses use phylogenetic meta-analysis models, despite widespread recognition of their importance (Chamberlain et al., 2012; Cinar et al., 2022).

Third, animal cognition research remains concentrated in Western countries, with limited international and interdisciplinary collaboration. This is likely driven by structural factors: researchers from low- and middle-income countries face barriers such as language obstacles (Ramírez-Castañeda, 2020; Vasconcelos et al., 2008), limited funding or insufficient infrastructure (Charani et al., 2022; Costello & Zumla, 2000; Skupien & Rüffin, 2020). Meta-analyses are less costly than experimental or field studies and, once the methodology is learned, can be conducted by researchers regardless of their location or resources. This makes meta-analysis an especially suitable approach for collaboration between researchers in both high-income and low- and middle-income countries. Including non-English studies in meta-analyses can lead to conclusions that differ from those based solely on English-language literature (Konno et al., 2020). This highlights the importance of collaborating with researchers from diverse countries to make meta-analyses more inclusive and comprehensive. Promoting multilingual dissemination and collaboration is therefore vital for building a more inclusive research community and for producing more robust findings.

While there are still notable areas for improvement in transparency and methodological reporting, our appraisal suggests that meta-analytical studies in animal cognition are already adopting several good practices. Compared to studies in ecology and evolution (O'Dea et al., 2021), these include more transparent reporting of screening procedures and more consistent treatment of publication bias and heterogeneity. These trends indicate a growing methodological awareness in the field and suggest that animal cognition research is making meaningful progress toward rigorous and transparent standards, in some respects keeping pace with or even exceeding practices in related biological disciplines.

Big Team Science projects have also begun to address some of these limitations by implementing collaborative, pre-registered, and standardised protocols. These initiatives promote open science and enable consistent, large-scale data collection and reporting. Importantly, many emphasise equity, diversity, and inclusion, thereby lowering participation barriers for researchers from the Global South. Big Team Science and meta-analytical studies are complementary: meta-analyses identify broad patterns and key questions, while Big Team Science projects directly test these questions under standardised conditions and provide detailed individual-level data.

Finally, several limitations should be noted. Although we used multiple databases and included non-English literature, complete comprehensiveness cannot be guaranteed. Search string variations and strict inclusion criteria may have excluded some relevant studies. Nonetheless, we hope that our study offers a relatively comprehensive and, more importantly, representative overview of meta-analytical research in animal cognition. Promoting transparency, data sharing, international collaboration, and broader taxonomic scope will be key to achieving a more reliable and inclusive understanding of cognitive abilities across species.

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7. Author contributions (CRediT taxonomy):

Ayumi Mizuno: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing - original draft, Writing - review & editing, Project administration.
Malgorzata Lagisz: Conceptualization, Methodology, Investigation, Validation, Writing – review & editing, Funding acquisition.
Pietro Pollo: Investigation, Writing - review & editing.
Lauren Guillette: Methodology, Supervision, Writing - review & editing, Funding acquisition.
Masayo Soma: Methodology, Supervision, Writing - review & editing.
Shinichi Nakagawa: Conceptualization, Methodology, Investigation, Supervision, Writing - review & editing, Funding acquisition.

8. Declaration of generative AI

During the preparation of this work, the author used ChatGPT-4o (OpenAI) to check grammar and spelling. After using this tool, the author carefully reviewed and edited the content as needed and takes full responsibility for the content of the published article.

9. Datasets

The data and scripts used in this study, as well as the lists of included and excluded papers, are available at: https://github.com/Ayumi-495/systematic_mapping_AnimCogn.

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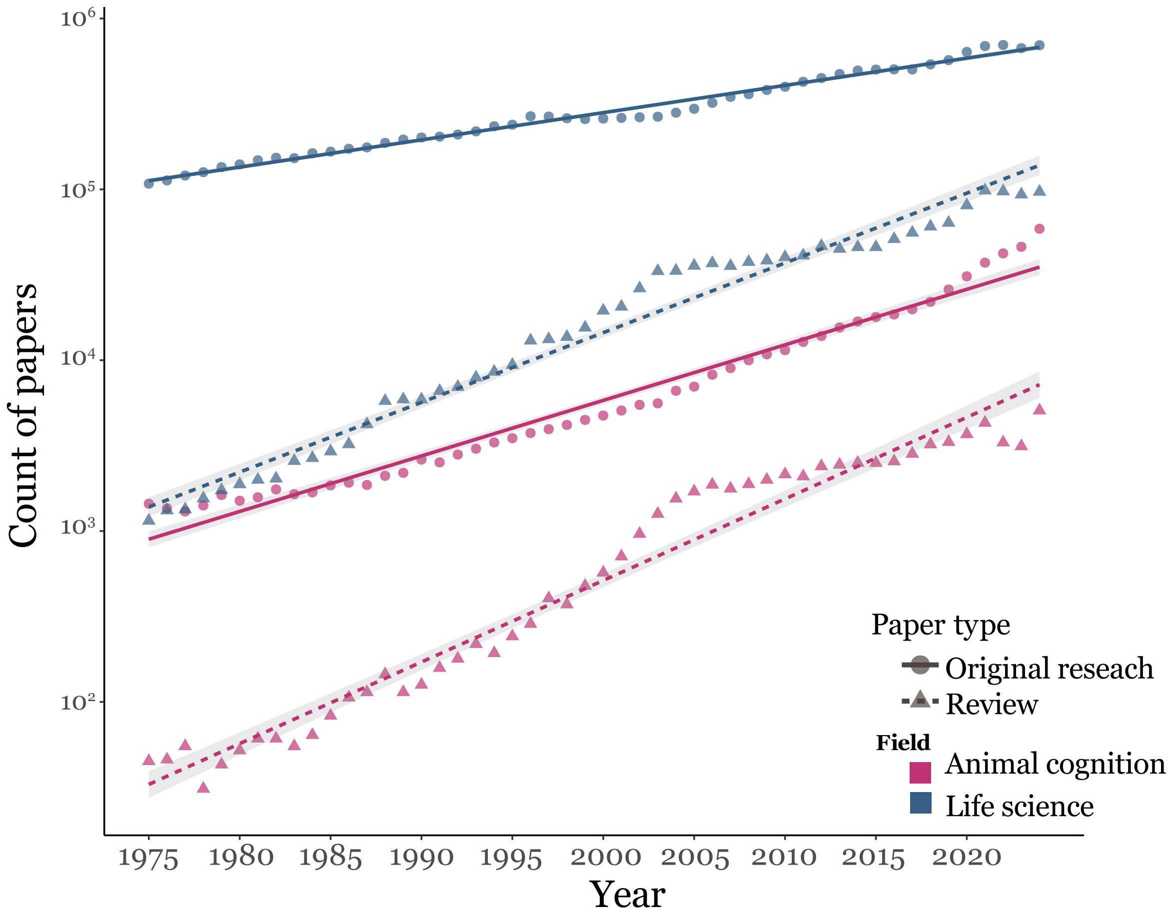

Figure 1. The number of papers on animal cognition published over the past 50 years (1975–2024), based on data from Scopus (obtained on April 1, 2025; methods in supplement material). The x-axis shows the publication years (1975–2024), and the y-axis indicates the cumulative number of papers published (on a log10 scale). Each point represents a category of publication, with shapes indicating publication type (circles for research articles and triangles for review articles) and colours representing research fields (pink for animal cognition and blue for life sciences). Solid lines represent trends in original research articles, and dashed lines represent trends in review articles. The overall growth rate of published articles in the life sciences is estimated at 3.9% per year for original research papers and 9.5% per year for review papers, including systematic reviews, meta-analyses, and narrative reviews. In contrast, within the field of animal cognition, both types of papers are growing at a faster rate: original research papers have an annual growth rate of 7.9%, while review papers grow at 10.1% per year. This indicates that the rate of increase (i.e., the slope of growth) is steeper for both original and review papers in animal cognition compared to the broader life sciences field, suggesting heightened research activity and interest in this specific area.

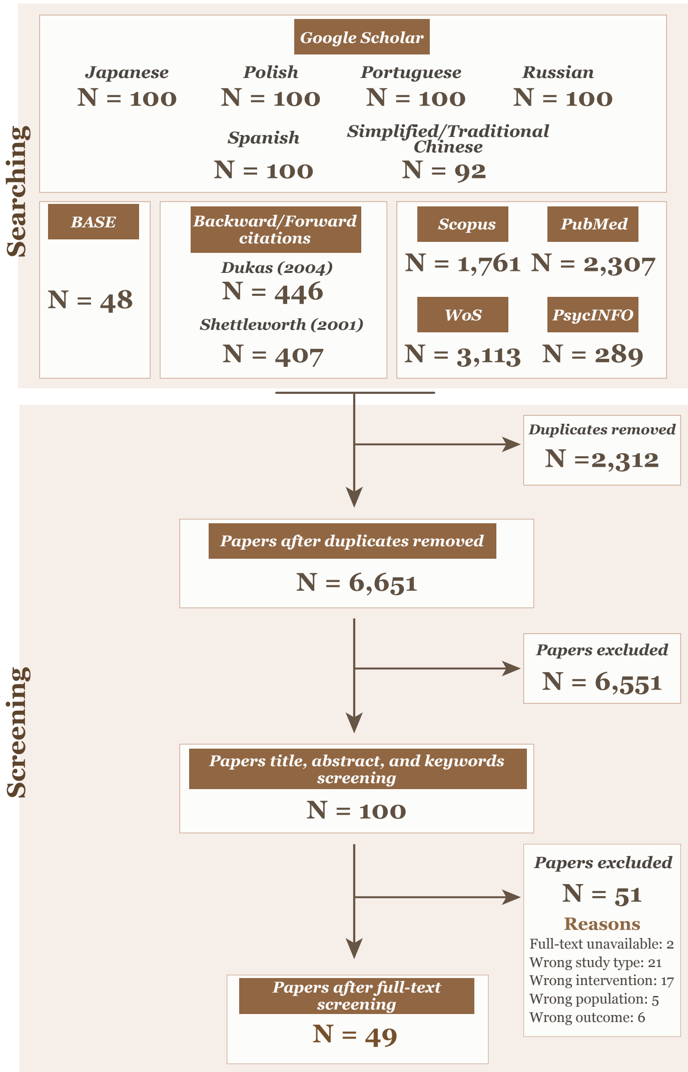

Figure 2. ROSES-like flowchart. This figure follows a Reporting Standards for Systematic Evidence Syntheses (ROSES)-like format, which provides a standardised and transparent structure for reporting systematic reviews and maps in environmental sciences and related disciplines. Although no established visualisation standard currently exists for systematic mapping in the field of animal cognition, we adapted the ROSES format to ensure clarity and transparency in documenting our review process. The flowchart outlines each stage of the literature selection process, beginning with the initial search across multiple databases (e.g., Scopus, Web of Science, PubMed, PsycINFO), grey literature sources (e.g., BASE), backward/forward citation tracking using Dukas (2004) and Shettleworth (2001), and non-English searches via Google Scholar (e.g., Japanese, Spanish, Polish) to final inclusion (bottom). A total of 8,963 records were retrieved. After removing 2,312 duplicates, 6,651 records remained for title, abstract, and keyword screening. Of these, 100 articles were selected for full-text screening, and 49 were retained in the final synthesis. Fifty-one articles were excluded due to reasons such as full-text unavailability (n = 2), wrong study type (n = 21), intervention (n = 17), population (n = 5), or outcome (n = 6).

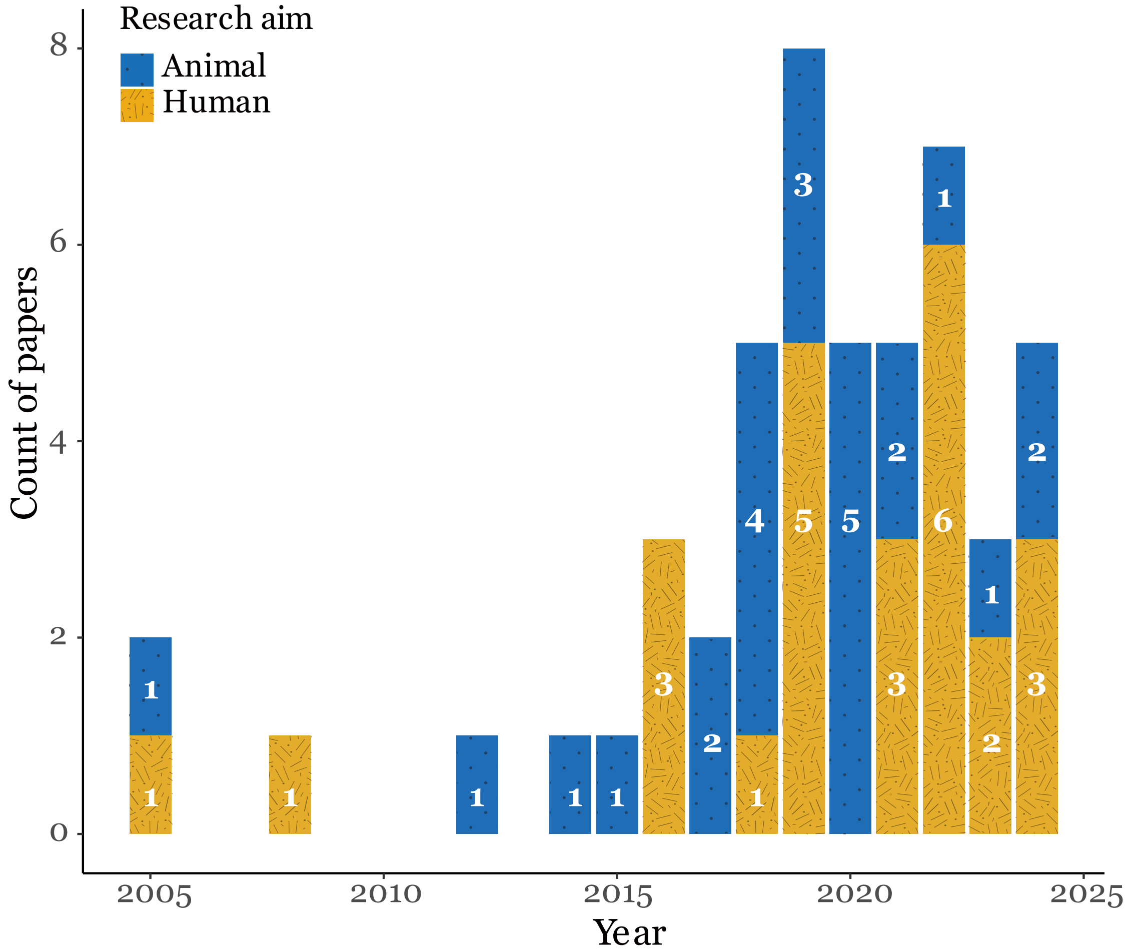

Figure 3. Number of meta-analytical studies published per year (2005-2025), categorised by research aim. "Animal" (blue bars with dots) refers to studies examining cognitive abilities and their evolutionary background in animals. "Human" (orange bars with hatch marks) refers to studies that use animal models to understand human cognition.

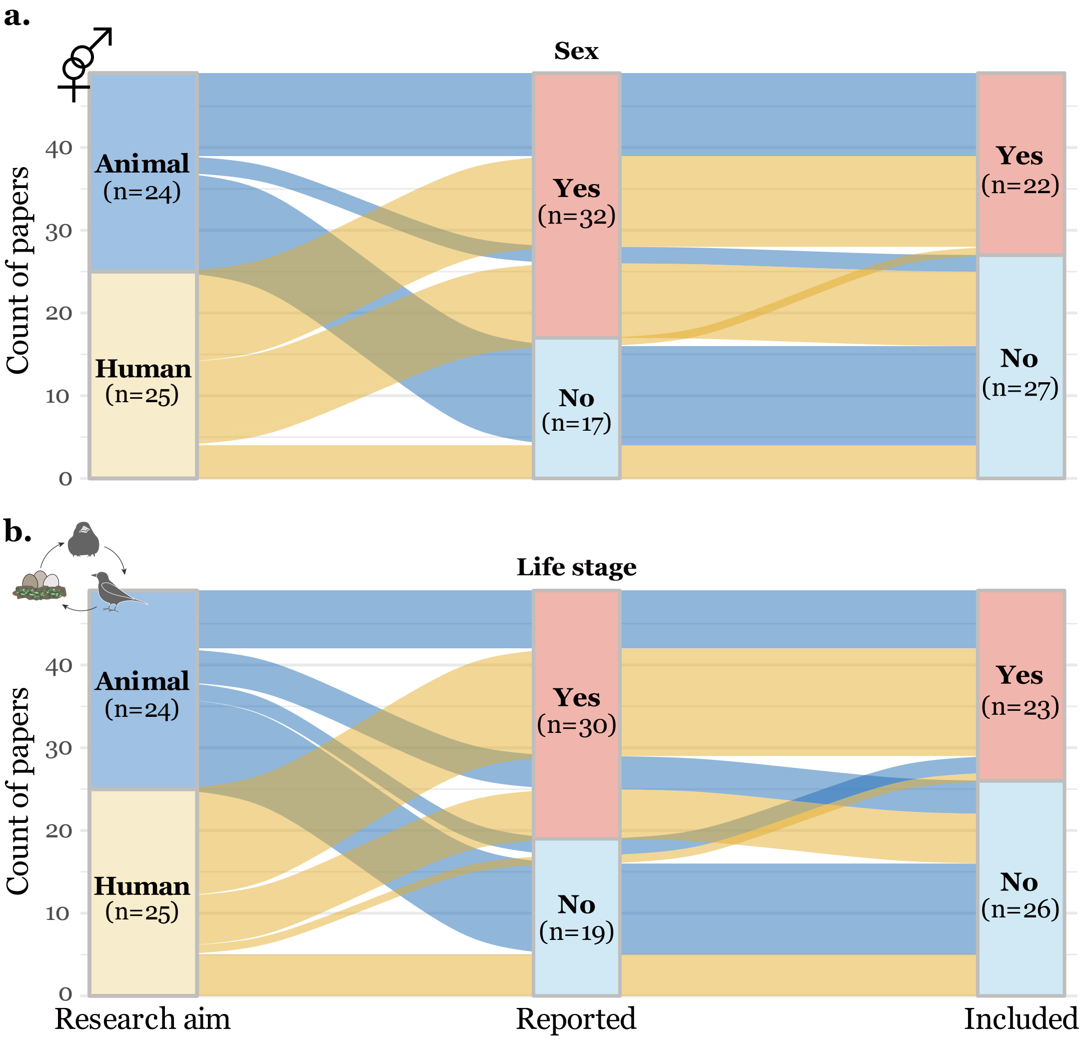

Figure 4. Reporting and analysis inclusion of study subjects sex and life stage information in meta-analytical studies, by research aim. This figure illustrates the flow of meta-analyses from their research aim (Animal-focused vs. Human-focused) to whether (a) sex and (b) life stage information was reported and subsequently included in the analysis. In both panels, meta-analyses with an animal cognition focus are shown in blue, and those using animal models to study human cognition are shown in yellow. The central bars indicate whether each variable was reported (red for "Yes", light blue for "No"), and the final bars indicate whether it was included in the analysis. The width of the connecting flows reflects the number of studies overlapping between levels of the three variables shown in each panel.

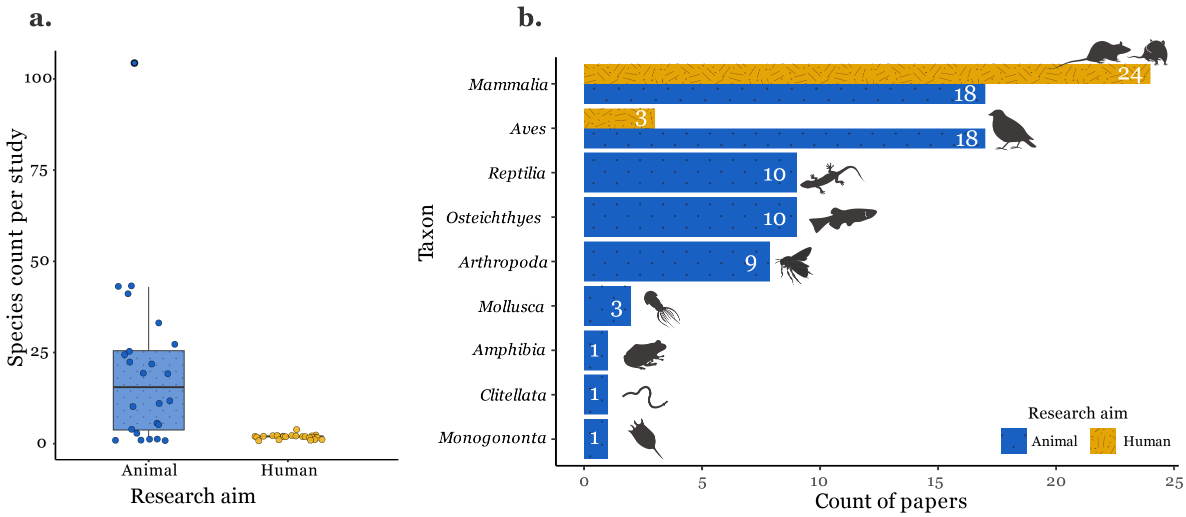

Figure 5. (a) Number of species included per meta-analytical study, categorised by research aim. Comparison between meta-analytical studies focused on animal cognition (blue) and those using animal models to study human cognition (yellow). Each point represents an individual meta-analytical study. Three meta-analytical studies for which the exact species count could not be determined are not shown. (b) Taxonomic coverage of meta-analyses by research aim. Bars represent the number of meta-analyses that included each animal taxon. Blue bars with dot patterns indicate meta-analyses focused on animal cognition ("Animal" research aim), while yellow bars with hatch patterns indicate studies using animal models to investigate human cognition ("Human" research aim). The numbers within the bars show the total count of meta-analyses for each combination of taxon and research aim.

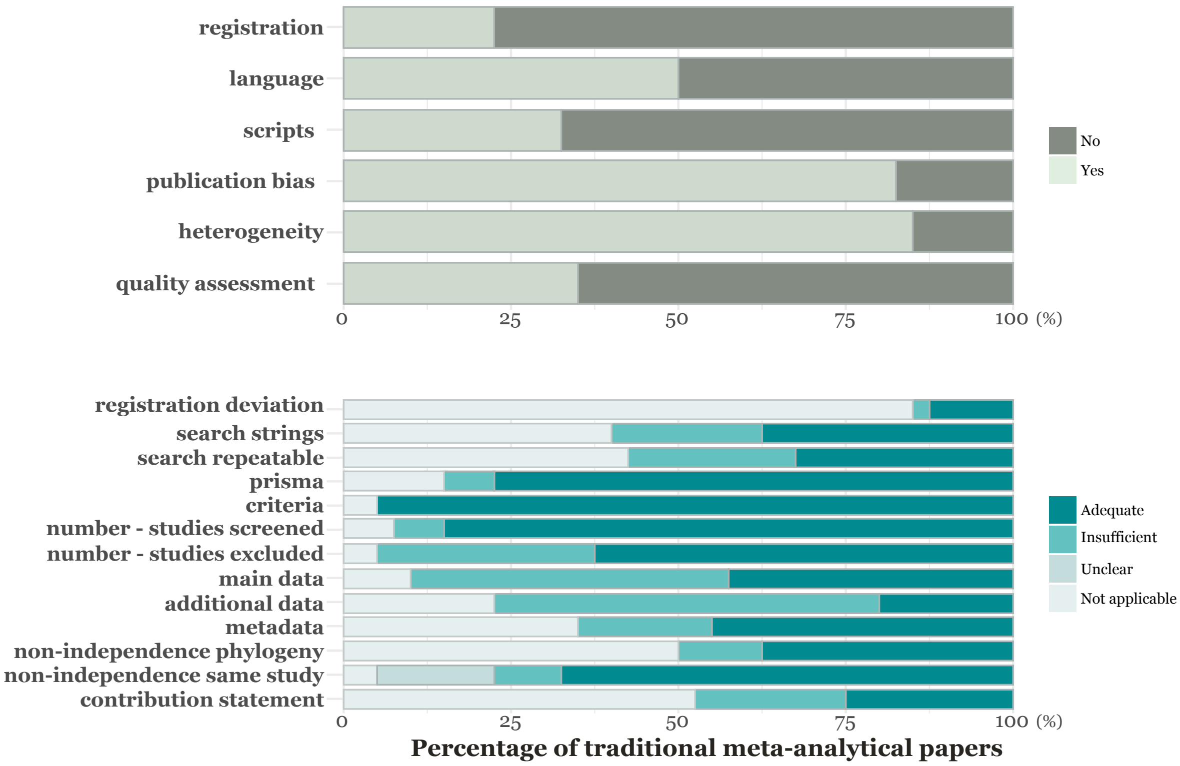

Figure 6. Appraisal of 40 animal cognition meta-analytical studies across 19 methodological elements. Adequate: The meta-analyses provide sufficient and clear information to assess or reproduce the analysis. Insufficient: Some necessary information is missing or not fully explained. Not applicable: the meta-analyses do not provide the necessary data, making it impossible to assess this criterion. Unclear: It is uncertain whether the necessary information is included, as the meta-analyses lack explicit details.

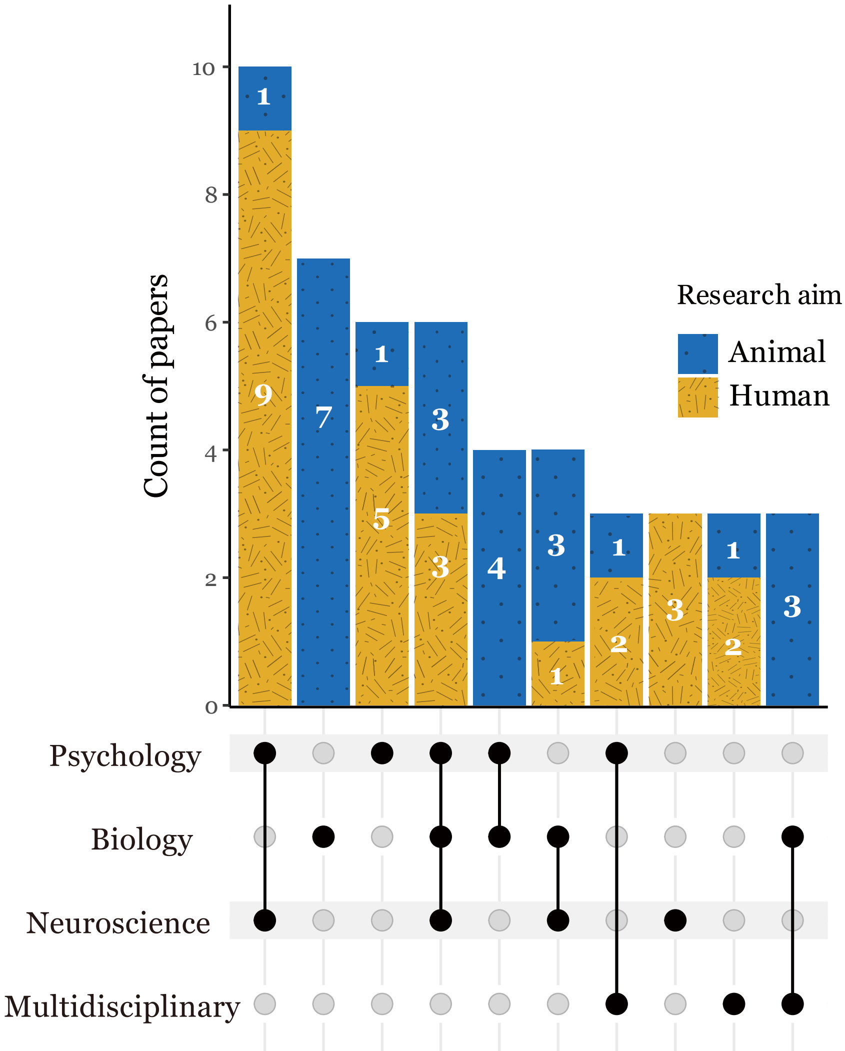

Figure 7. Meta-analytical studies categorised by research aim and journal disciplinary scope. Top panel: Bar plot showing the number of meta-analyses published in each disciplinary category, grouped by research aim. Meta-analyses classified as "Animal" (blue bars with dots) investigated cognitive abilities and their diversity or evolutionary background in non-human animals. Meta-analyses classified as "Human" (orange bars with hatch marks) used animal models to study human cognition. Bottom panel: UpSet-style plot showing the disciplinary scope of the journals in which the meta-analyses were published. Black dots indicate the inclusion of a discipline (e.g., biology, psychology, neuroscience), and vertical lines connect multiple disciplines associated with a single journal. For example, studies published in journals spanning both biology and neuroscience are represented by connected dots in those rows. The "Multidisciplinary" category includes journals with a broad scope (e.g., *PLOS One* and *Royal Society Open Science*). The disciplinary categorisation of journals was based on Web of Science categories and each journal's stated aims and scope.

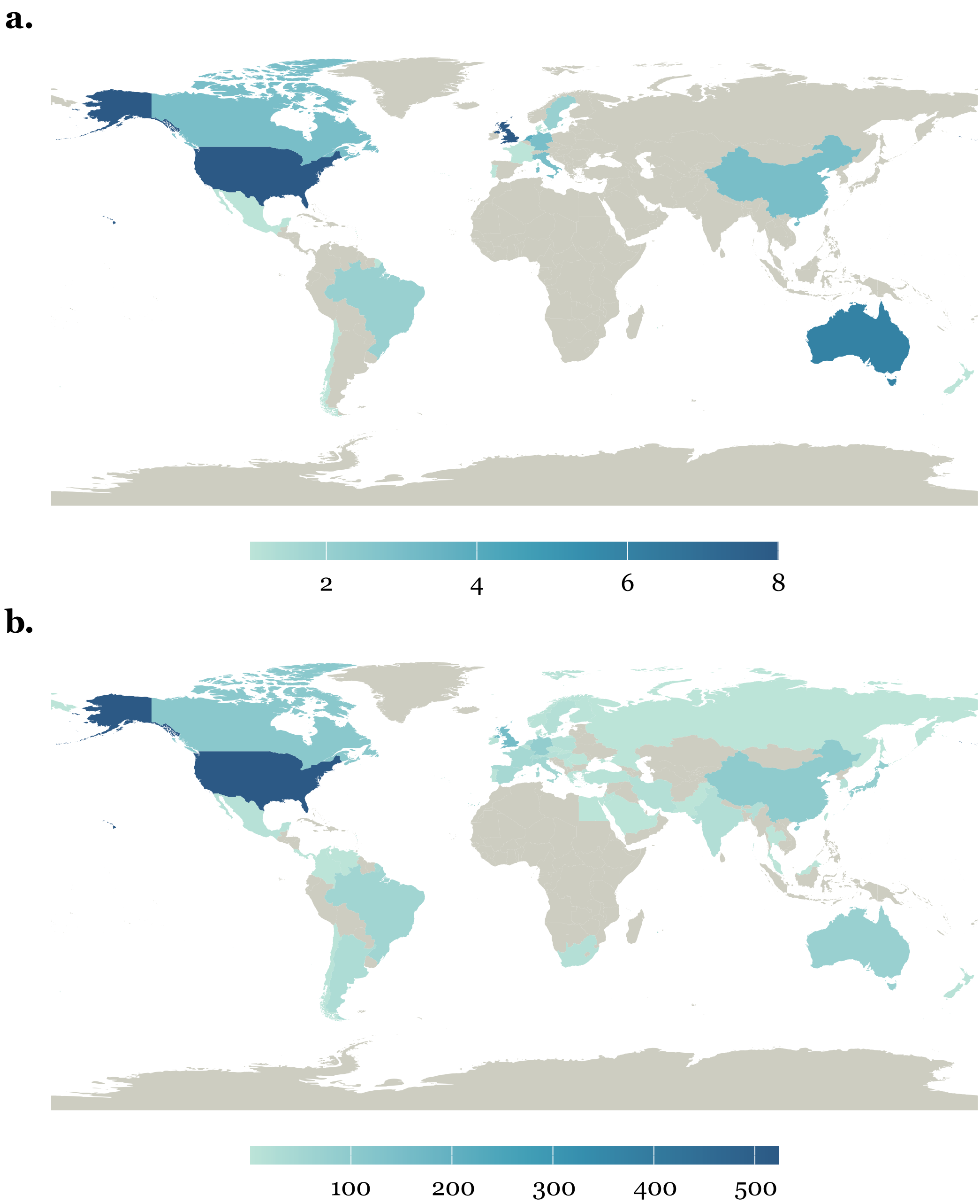

Figure 8. Heat map of the first author's affiliation. The world map displays the number of first authors' affiliations at the country level for (a) meta-analytical and (b) primary studies on animal cognition. Grey indicates countries with no first authors in our dataset.

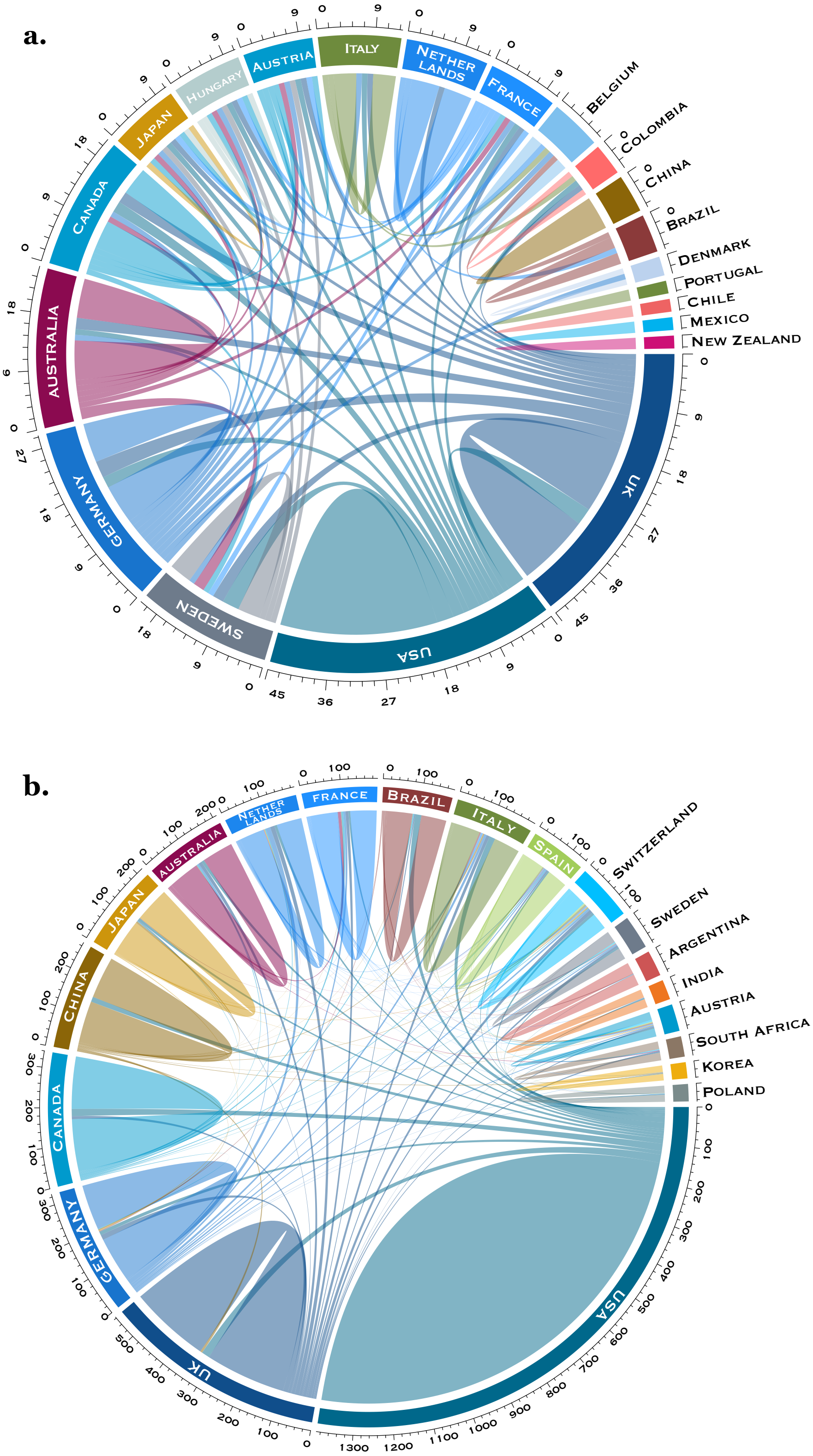

Figure 9. A chord diagram illustrating collaborations between countries of affiliation of the authors, ordered by the number of countries from most to least. (a) shows the meta-analytical study level, and (b) illustrates the primary study level.

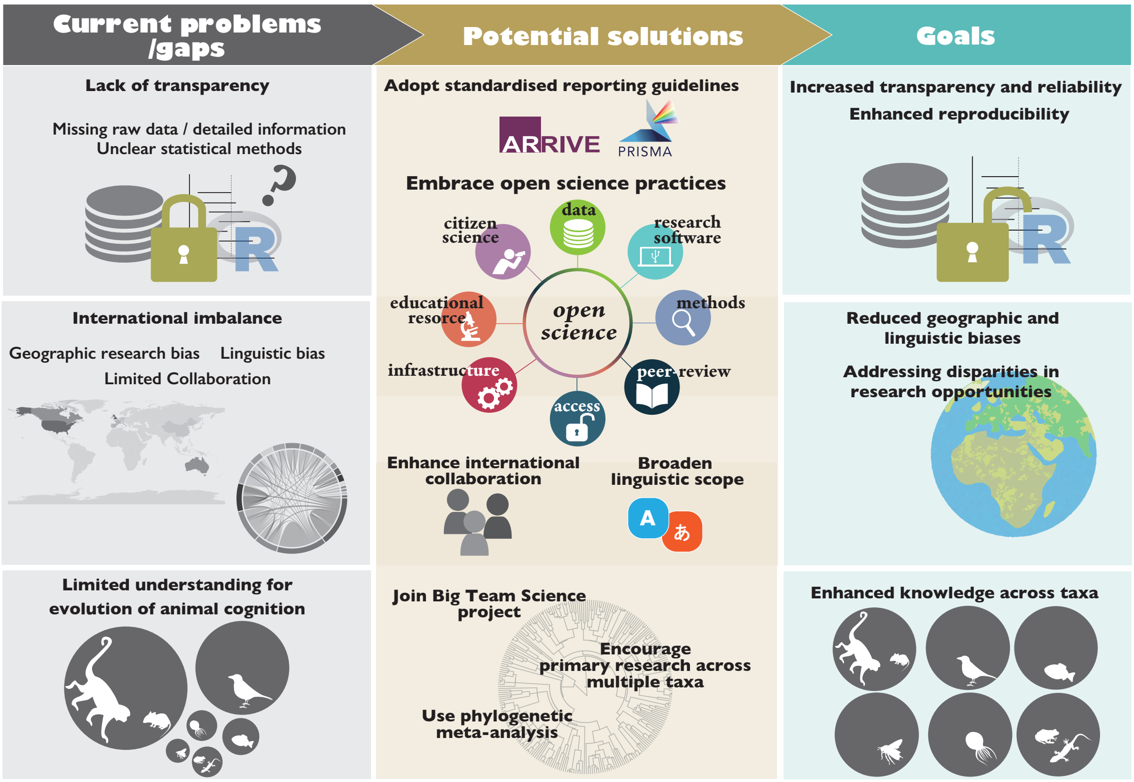

Figure 10. Conceptual diagram illustrating current problems, potential solutions, and ultimate goals in meta-analytical studies on animal cognition. The figure is organised into three columns: The left column summarises key challenges currently facing the field, including lack of transparency, international and linguistic imbalances, and limited understanding of the evolution of animal cognition. The middle column presents potential solutions to these issues, such as adopting standardised reporting guidelines (e.g., ARRIVE, PRISMA), embracing open science practices (including data sharing, research software, and citizen science), enhancing international collaboration, broadening linguistic scope, joining Big Team Science projects, and utilising phylogenetic meta-analysis. The right column shows the intended goals of these strategies: increased transparency and reproducibility, reduction of geographic and linguistic biases, greater equity in research opportunities, and enhanced knowledge of animal cognition across a broader range of taxa.

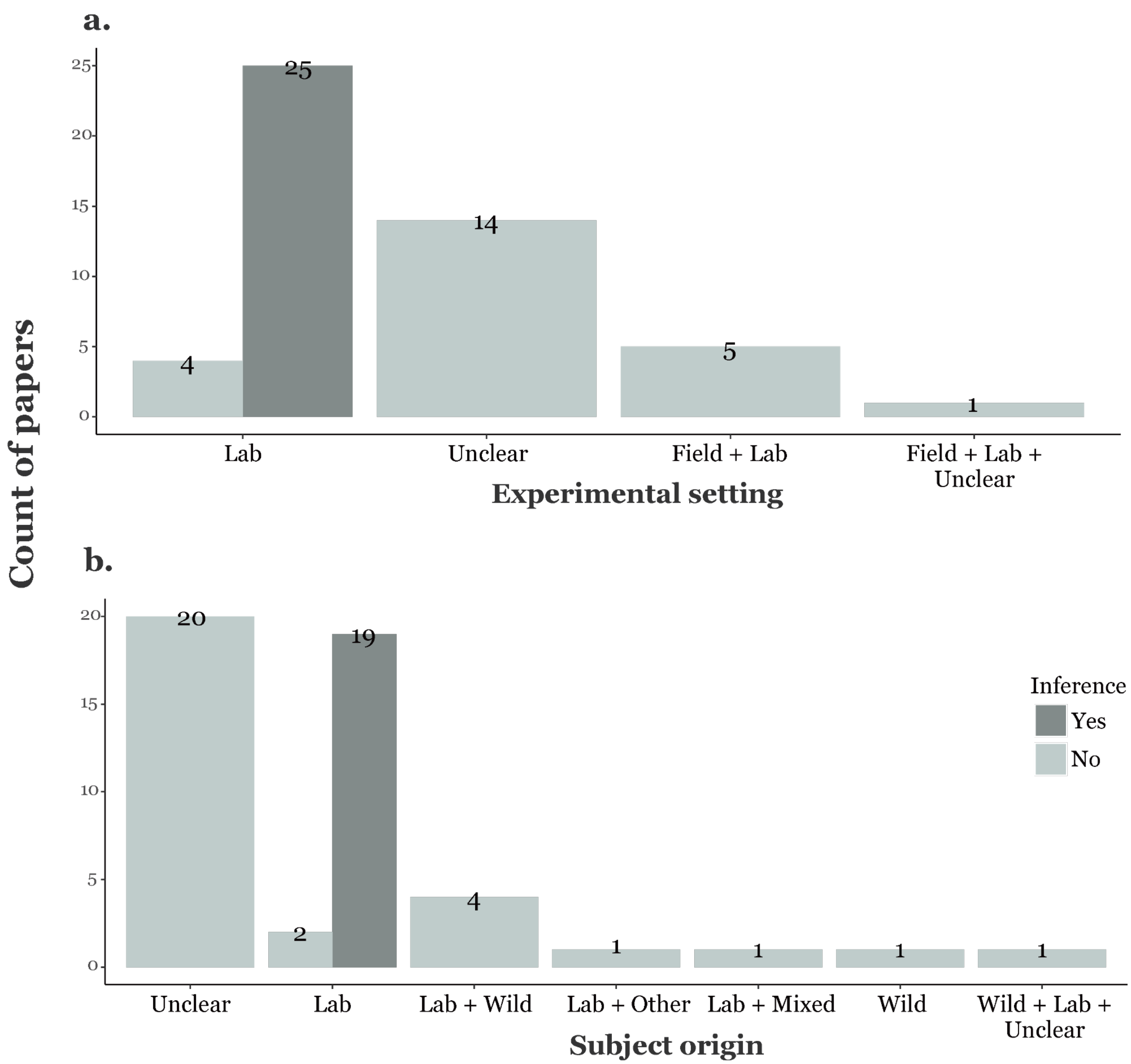

Figure S1. Summary of study characteristics in the meta-analytical studies. The figures represent the distribution of (a) experimental settings, categorised as "Lab", "Unclear", "Field + Lab", and "Field + Lab + Unclear" and (b) subject origins, categorised into "Unclear", "Lab", "Lab + Wild", and other minor categories. Darker bars represent cases where inference was made based on available information, while lighter bars indicate stated information in the papers.

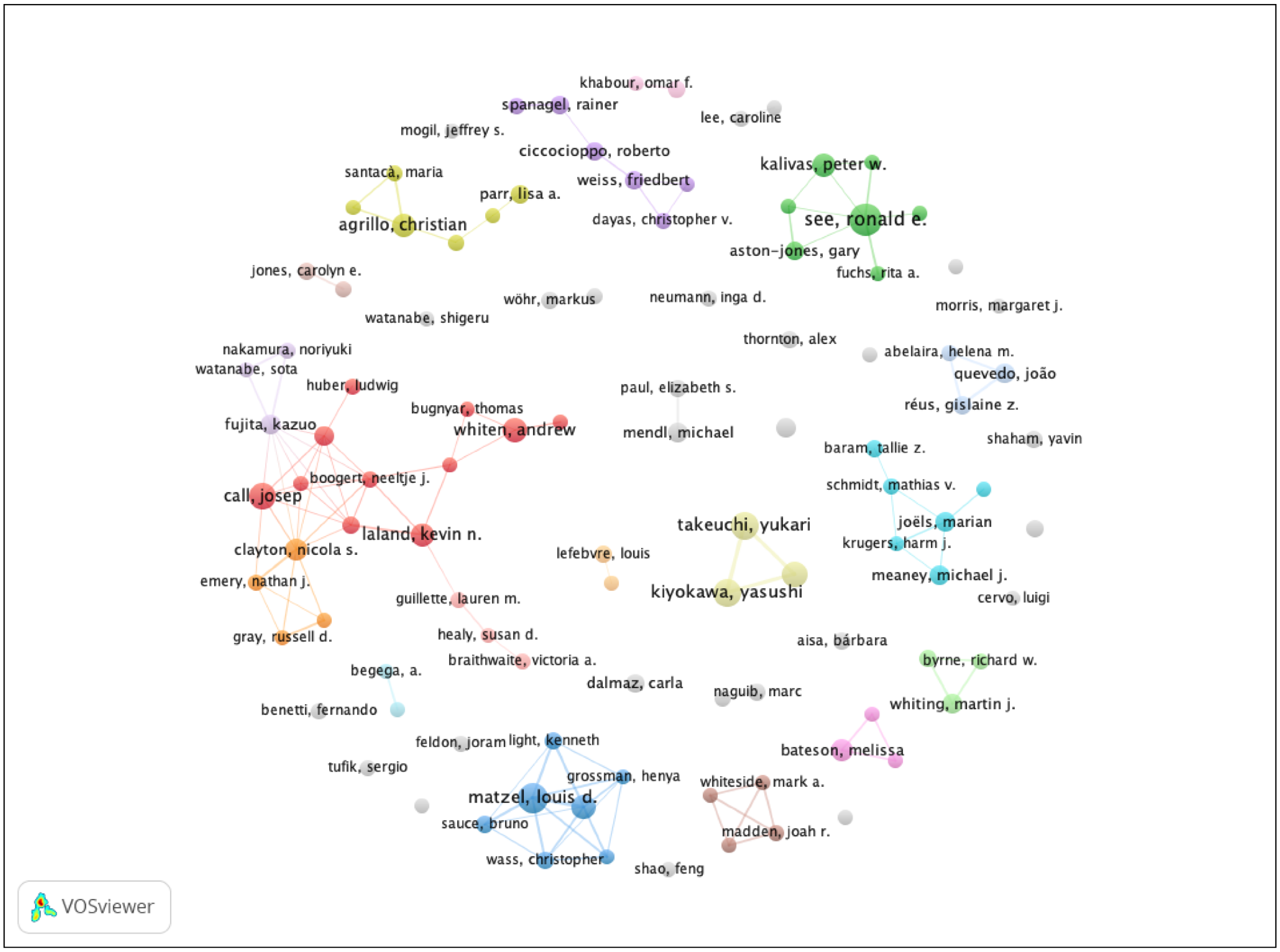

Figure S2. Co-authorship network among authors of primary studies on animal cognition. This figure was generated using VOSviewer, which shows clusters of researchers based on co-authorship patterns in primary studies included in 49 meta-analytical papers we found. Each node represents an individual author, and links between nodes indicate co-authored publications. The size of each node reflects the total link strength (i.e., number of co-authored studies), and colours denote distinct clusters or collaborative groups identified by the clustering algorithm. Authors with closer proximity have stronger co-authorship connections.

Table S1. Search strings

Database	String
Scopus	(((TITLE-ABS-KEY ((("meta-analy*" OR "meta-regres*" OR "metanal*" OR "metaregres*" OR (quantitativ* W/3 synthes*)) AND (cognit* OR learn* OR memor* OR decision-making* OR "decision making*" OR conditioned* OR conditioning OR recognition* OR discriminat* OR reasoning OR forget* OR "tool us*" OR "tool-us*" OR "object permanence" OR pavlovian OR operant OR instrumental OR habitat* OR generalisation* OR generalization* OR exploration OR teaching OR imitat* OR emula* OR innovat* OR "problem solving" OR "problem-solving" OR "social facilitation" OR "socially influenced" OR inference* OR reinforcement* OR intelligence OR personalit* OR "behavioural syndrom*" OR "behavioral syndrom*" OR extinction) AND (animal* OR ape* OR avian OR bird* OR corvid* OR jay* OR bee* OR mouse OR mice OR non-human OR "non human" OR primate* OR monkey* OR rat OR rats OR rodent* OR pre-clinical OR reptile* OR lizard* OR squamata OR amphib* OR fish* OR insect* OR fly OR flies OR diptera OR beetle OR wasp OR monkey OR chick* OR aves OR pig* OR horse* OR dog* OR cat* OR dolphin* OR orca* OR whale* OR octopus* OR squid* OR canidae OR Felidae OR parrot* OR parakeet*)) AND NOT (child* OR cross-section* OR school* OR education* OR hospital* OR clinical* OR genom* OR disease* OR nano* OR cancer* OR stroke OR student* OR patient* OR injur* OR medic* OR gene OR genes OR cyber* OR technolog* OR city OR cities OR urban* OR team OR disab* OR teen* OR soil OR neural OR plant* OR forest* OR disaster* OR neurocognition OR person OR profession* OR pedagog* OR education* OR industr* OR fisheries OR "public health" OR women OR men))))) AND (EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "ENGI") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "COMP") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "BUSI") OR EXCLUDE (SUBJAREA , "ECON")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")
PubMed	("meta analy*"[Title/Abstract] OR "meta regres*"[Title/Abstract] OR "methanal*"[Title/Abstract] OR "metaregres*"[Title/Abstract] OR (“quantitative synthesis”[Title/Abstract:~3]) OR “quantitative syntheses”[Title/Abstract:~3] OR “quantitative synthesize”[Title/Abstract:~3] OR “quantitative synthesizes”[Title/Abstract:~3] OR “quantitative synthesizing”[Title/Abstract:~3] OR “quantitative synthesised”[Title/Abstract:~3] OR “quantitative synthesising”[Title/Abstract:~3] OR “quantitatively synthesis”[Title/Abstract:~3] OR “quantitatively syntheses”[Title/Abstract:~3] OR

	“quantitatively synthesize”[Title/Abstract:~3] OR “quantitatively synthesizes”[Title/Abstract:~3] OR “quantitatively synthesizing”[Title/Abstract:~3] OR “quantitatively synthesised”[Title/Abstract:~3] OR “quantitatively synthesising”[Title/Abstract:~3]) AND ("cognit*"[Title/Abstract] OR "learn*"[Title/Abstract] OR "memor*"[Title/Abstract] OR "decision making*"[Title/Abstract] OR "decision making*"[Title/Abstract] OR "conditioned*"[Title/Abstract] OR ("conditioning, psychological"[MeSH Terms] OR ("conditioning"[Title/Abstract] AND "psychological"[Title/Abstract]) OR "psychological conditioning"[Title/Abstract] OR "conditioned"[Title/Abstract] OR "conditioning"[Title/Abstract] OR "conditionings"[Title/Abstract]) OR "recognition*"[Title/Abstract] OR "discriminat*"[Title/Abstract] OR ("reasonableness"[Title/Abstract] OR "reasoned"[Title/Abstract] OR "reasoner"[Title/Abstract] OR "reasoners"[Title/Abstract] OR "reasoning"[Title/Abstract] OR "reasonings"[Title/Abstract]) OR "forget*"[Title/Abstract] OR "tool us*"[Title/Abstract] OR "tool us*"[Title/Abstract] OR "object permanence"[Title/Abstract] OR ("pavlovian"[Title/Abstract] OR "pavlovians"[Title/Abstract]) OR ("operant"[Title/Abstract] OR "operants"[Title/Abstract]) OR ("instrumental"[Title/Abstract] OR "instrumentally"[Title/Abstract] OR "instrumentals"[Title/Abstract]) OR "habitat*"[Title/Abstract] OR "generalisation*"[Title/Abstract] OR ("exploration"[Title/Abstract] OR "explorations"[Title/Abstract] OR "explorative"[Title/Abstract] OR "explore"[Title/Abstract] OR "explored"[Title/Abstract] OR "explores"[Title/Abstract] OR "exploring"[Title/Abstract]) OR ("education"[MeSH Subheading] OR "education"[Title/Abstract] OR "teaching"[Title/Abstract] OR "teaching"[MeSH Terms] OR "teaches"[Title/Abstract] OR "teach"[Title/Abstract] OR "teachings"[Title/Abstract] OR "imitat*"[Title/Abstract] OR "emula*"[Title/Abstract] OR "innovat*"[Title/Abstract] OR "problem-solving"[Title/Abstract] OR "problem-solving"[Title/Abstract] OR "social facilitation"[Title/Abstract] OR "socially influenced"[Title/Abstract] OR "inference*"[Title/Abstract] OR "reinforcement*"[Title/Abstract] OR ("intelligence"[MeSH Terms] OR "intelligence"[Title/Abstract] OR "intelligences"[Title/Abstract] OR "intelligent"[Title/Abstract] OR "intelligently"[Title/Abstract] OR "intelligibilities"[Title/Abstract] OR "intelligibility"[Title/Abstract] OR "intelligible"[Title/Abstract]) OR "personalit*"[Title/Abstract] OR "behaviour syndrome"[Title/Abstract] OR "behavior syndrome"[Title/Abstract] OR "extinction, psychological"[MeSH Terms] OR ("extinction"[All Fields] AND "psychological"[All Fields]) OR "psychological extinction"[All Fields] OR "extinction"[All Fields] OR "extinctions"[All Fields]) AND ("animal*"[Title/Abstract] OR ("hominidae"[MeSH Terms] OR "hominidae"[Title/Abstract] OR "ape"[Title/Abstract]) OR ("hominidae"[MeSH Terms] OR "hominidae"[Title/Abstract] OR

	"apes"[Title/Abstract]) OR ("birds"[MeSH Terms] OR "birds"[Title/Abstract] OR "avian"[Title/Abstract] OR "avians"[Title/Abstract]) OR "bird*"[Title/Abstract] OR "corvid*"[Title/Abstract] OR "jay"[Title/Abstract] OR "jays"[Title/Abstract] OR "bee"[Title/Abstract] OR ("bees"[MeSH Terms] OR "bees"[Title/Abstract]) OR ("mice"[MeSH Terms] OR "mice"[Title/Abstract] OR "mouse"[Title/Abstract] OR "mouse s"[Title/Abstract] OR "mouses"[Title/Abstract]) OR ("mice"[MeSH Terms] OR "mice"[Title/Abstract]) OR "non-human"[Title/Abstract] OR "non-human"[Title/Abstract] OR "primate*"[Title/Abstract] OR ("rats"[MeSH Terms] OR "rats"[Title/Abstract] OR "rat"[Title/Abstract]) OR ("rats"[MeSH Terms] OR "rats"[Title/Abstract]) OR "rodent*"[Title/Abstract] OR "pre-clinical"[Title/Abstract] OR "reptile*"[Title/Abstract] OR "lizard*"[Title/Abstract] OR "squamata"[Title/Abstract] OR "amphib*"[Title/Abstract] OR "fish*"[Title/Abstract] OR "insect*"[Title/Abstract] OR ("fly austin"[Journal] OR "fly"[Title/Abstract]) OR ("diptera"[MeSH Terms] OR "diptera"[Title/Abstract] OR "flies"[Title/Abstract]) OR ("diptera"[MeSH Terms] OR "diptera"[Title/Abstract] OR "dipteras"[Title/Abstract]) OR ("beetle s"[Title/Abstract] OR "coleoptera"[MeSH Terms] OR "coleoptera"[Title/Abstract] OR "beetle"[Title/Abstract] OR "beetles"[Title/Abstract]) OR ("wasps"[MeSH Terms] OR "wasps"[Title/Abstract] OR "wasp"[Title/Abstract]) OR ("haplorhini"[MeSH Terms] OR "haplorhini"[Title/Abstract] OR "monkey"[Title/Abstract] OR "monkeys"[Title/Abstract] OR "monkey s"[Title/Abstract]) OR "chick*"[Title/Abstract] OR ("birds"[MeSH Terms] OR "birds"[Title/Abstract] OR "aves"[Title/Abstract]) OR ("parrot*"[Title/Abstract] OR "parrot*"[MeSH Terms]) OR ("parakeet*"[Title/Abstract] OR "parakeet*"[MeSH Terms]) OR ("pig"[Title/Abstract] OR "swine"[MeSH Terms] OR "pigs"[Title/Abstract]) OR ("horse*"[Title/Abstract] OR "horse*"[MeSH Terms]) OR ("dog"[Title/Abstract] OR "dogs"[Title/Abstract] OR "dogs"[MeSH Terms]) OR "canidae"[MeSH Terms] OR "canidae"[All Fields] OR ("cat"[Title/Abstract] OR "cats"[Title/Abstract] OR "cats"[MeSH Terms]) OR "felidae"[MeSH Terms] OR "felidae"[All Fields] OR ("dolphin*"[Title/Abstract] OR "dolphin*"[MeSH Terms] OR "orca*"[Title/Abstract]) OR ("whale*"[Title/Abstract] OR "whale*"[MeSH Terms]) OR ("octopus*"[Title/Abstract] OR "squid*"[Title/Abstract] OR "Cephalopoda"[MeSH Terms]))) NOT ("child*"[Title/Abstract] OR "cross section*"[Title/Abstract] OR "school*"[Title/Abstract] OR "education*"[Title/Abstract] OR "hospital*"[Title/Abstract] OR "clinical"[Title/Abstract] OR "genom*"[Title/Abstract] OR "disease*"[Title/Abstract] OR "nano*"[Title/Abstract] OR "cancer*"[Title/Abstract] OR ("stroke"[MeSH Terms] OR "stroke"[Title/Abstract] OR "strokes"[Title/Abstract] OR "stroke s"[Title/Abstract]) OR "student*"[Title/Abstract] OR "patient*"[Title/Abstract] OR

	"therap*"[Title/Abstract] OR "injur*"[Title/Abstract] OR "medic*"[Title/Abstract] OR ("genes"[MeSH Terms] OR "genes"[Title/Abstract] OR "gene"[Title/Abstract]) OR ("gene s"[Title/Abstract] OR "genes"[MeSH Terms] OR "genes"[Title/Abstract]) OR "cyber*"[Title/Abstract] OR "technolog*"[Title/Abstract] OR ("cities"[MeSH Terms] OR "cities"[Title/Abstract] OR "city"[Title/Abstract]) OR ("cities"[MeSH Terms] OR "cities"[Title/Abstract] OR "city s"[Title/Abstract]) OR "urban*"[Title/Abstract] OR "team"[Title/Abstract] OR "disab*"[Title/Abstract] OR "teen*"[Title/Abstract] OR ("soil"[MeSH Terms] OR "soil"[Title/Abstract]) OR ("neural"[Title/Abstract] OR "neuralization"[Title/Abstract] OR "neuralize"[Title/Abstract] OR "neuralized"[Title/Abstract] OR "neuralizes"[Title/Abstract] OR "neuralizing"[Title/Abstract] OR "neurally"[Title/Abstract]) OR "plant*"[Title/Abstract] OR "forest*"[Title/Abstract] OR "disaster*"[Title/Abstract] OR ("neurocognition"[Title/Abstract] OR "neurocognitive"[Title/Abstract] OR "neurocognitively"[Title/Abstract]) OR ("person s"[Title/Abstract] OR "personable"[Title/Abstract] OR "personableness"[Title/Abstract] OR "personal"[Title/Abstract] OR "personalisation"[Title/Abstract] OR "personalise"[Title/Abstract] OR "personalised"[Title/Abstract] OR "personalising"[Title/Abstract] OR "personality"[MeSH Terms] OR "personality"[Title/Abstract] OR "personalities"[Title/Abstract] OR "personality s"[Title/Abstract] OR "personalization"[Title/Abstract] OR "personalize"[Title/Abstract] OR "personalized"[Title/Abstract] OR "personalizes"[Title/Abstract] OR "personalizing"[Title/Abstract] OR "personally"[Title/Abstract] OR "personals"[Title/Abstract] OR "persons"[MeSH Terms] OR "persons"[Title/Abstract] OR "person"[Title/Abstract]) OR "profession*"[Title/Abstract] OR "pedagog*"[Title/Abstract] OR "education*"[Title/Abstract] OR "industr*"[Title/Abstract] OR ("fisheries"[MeSH Terms] OR "fisheries"[Title/Abstract] OR "fishery"[Title/Abstract] OR "fisher's"[Title/Abstract] OR "public health"[Title/Abstract] OR ("womans"[Title/Abstract] OR "women"[MeSH Terms] OR "women"[Title/Abstract] OR "woman"[Title/Abstract] OR "women s"[Title/Abstract] OR "womens"[Title/Abstract]) OR ("men"[MeSH Terms] OR "men"[Title/Abstract])) OR "services"[Title/Abstract] OR "sports"[Title/Abstract] OR "sport"[Title/Abstract] OR "people"[Title/Abstract] OR "human health"[Title/Abstract] OR "respondents"[Title/Abstract] OR "participant"[Title/Abstract] OR "participants"[Title/Abstract] OR "racial"[Title/Abstract] OR "ethnic"[Title/Abstract] OR "workplace"[Title/Abstract] OR "lifestyle"[Title/Abstract] OR "racial"[Title/Abstract])
Web of Science	(TS = (("meta-analy*" OR "meta-regres*" OR "metanal*" OR "metaregres*" OR (quantitativ* NEAR/3 synthes*)) AND (cognit* OR learn* OR memor* OR decision-making* OR "decision

	making*" OR conditioned* OR conditioning OR recognition* OR discriminat* OR reasoning OR forget* OR "tool us*" OR "tool-us*" OR "object permanence" OR pavlovian OR operant OR instrumental OR habitat* OR generalisation* OR generalization* OR exploration OR teaching OR imitat* OR emula* OR innovat* OR "problem solving" OR "problem-solving" OR "social facilitation" OR "socially influenced" OR inference* OR reinforcement* OR intelligence OR personalit* OR "behavioural syndrom*" OR "behavioral syndrom*" OR extinction*) AND (animal* OR ape* OR avian OR bird* OR corvid* OR jay* OR bee* OR mouse OR mice OR non-human OR "non human" OR primate* OR monkey* OR rat OR rats OR rodent* OR pre-clinical OR reptile* OR lizard* OR squamata OR amphib* OR fish* OR insect* OR fly OR flies OR diptera OR beetle OR wasp OR monkey OR chick* OR aves OR pig* OR horse* OR dog* OR cat* OR dolphin* OR orca* OR whale* OR octopus* OR squid* OR canidae OR felidae OR parrot* OR parakeet*) NOT (child* OR cross-section* OR school* OR education* OR hospital* OR clinical OR genom* OR disease* OR nano* OR cancer* OR stroke OR student* OR patient* OR injur* OR medic* OR gene OR genes OR cyber* OR technolog* OR city OR cities OR urban* OR team OR disab* OR teen* OR soil OR neural OR plant* OR forest* OR disaster* OR neurocognition OR person OR profession* OR pedagog* OR education* OR industr* OR fisheries OR "public health" OR women OR men)) NOT SU = Business & Economics NOT SU = Operations Research & Management Science NOT SU = Sport Sciences NOT SU = Mathematical & Computational Biology NOT SU = Mathematics NOT SU = Nuclear Medicine & Medical Imaging NOT SU = Surgery NOT SU = Medical General Internal) NOT (SJ = ("PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH" OR "COMPUTER SCIENCE" OR "GENERAL INTERNAL MEDICINE" OR "EDUCATION EDUCATIONAL RESEARCH" OR "ENGINEERING" OR "PHYSICS" OR "SUBSTANCE ABUSE" OR "TOXICOLOGY" OR "PHYSICAL GEOGRAPHY"))
PsycINFO	(meta-analysis OR meta regression OR meta-regression OR quantitative study) AND (animal OR animals OR non-human OR non human) AND (cognition OR learning OR memory OR decision-making OR decision making)
BASE	Meta-analysis AND animal AND cognition AND (learning OR memory OR decision-making OR “decision-making”) doctype:18*

Google Scholar - Japanese	メタ解析|メタ分析 動物 認知|学習|記憶|意思決定
Google Scholar - Polish	metaanaliza zwierzę poznanie|“uczenie się”|pamięć|“podejmowanie decyzji”
Google Scholar - Portuguese	meta-análise animal cognição|aprendizagem|aprendizado|memória|“tomada de decisão”
Google Scholar - Russian	мета-анализ животные познание|обучение|память|“принятие решений”|“принятие решений”
Google Scholar - Spanish	meta-análisis animal cognición|aprendizaje|memoria|“toma de decisiones”
Google Scholar - Simplified Chinese	元分析|荟萃分析 动物 认知|学习|记忆|决策
Google Scholar - Traditional Chinese	元分析|薈萃分析 動物 認知|認識|學習|記憶|決策

Table S2. Population, Intervention, Comparator, Outcome, and Study type

Population	Non-human animals
Intervention	Cognition-related experiments, specifically learning (e.g., Aesop’s fable paradigm, maze tasks, observer-demonstrator paradigm), memory (e.g., maze tasks, spatial memory tasks) and decision-making (e.g., observer-demonstrator paradigm)
Comparator	Group/subjects that were not trained
Outcome	Any outcomes, including patterns and consequences on topics of animal cognition
Study type	Meta-analytical study, or a study that uses empirical data from multiple studies to make a quantitative conclusion

Supplemental methods

Data collection and visualisation for Figure 1

We extracted bibliographic data from Scopus on April 1, 2025. We used Boolean-style search strings targeting original research and review articles related to animal cognition and general life sciences (see below for full search strings). The search was restricted to documents published between 1975 and 2024. R (R Core Team, 2024) and the ggplot2 package (Wickham, 2016) were used to illustrate trends.

Animal cognition research

Original papers:

(TITLE-ABS-KEY(("cognition" OR "cognitive" OR "learn*" OR "memor*" OR "decision making" OR "decision-making" OR "intelligence*") AND (animal* OR mammal* OR bird* OR Ave* OR "fish*" OR "reptile*" OR "amphibian*" OR "invertebrate*" OR "primate*" OR "ape*" OR "cephalopod*")) AND (LIMIT-TO (DOCTYPE,"ar")))

Review papers:

(TITLE-ABS-KEY(("cognition" OR "cognitive" OR "learn*" OR "memor*" OR "decision making" OR "decision-making" OR "intelligence*") AND (animal* OR mammal* OR bird* OR Ave* OR "fish*" OR "reptile*" OR "amphibian*" OR "invertebrate*" OR "primate*" OR "ape*" OR "cephalopod*")) AND (LIMIT-TO (DOCTYPE,"re")))

Life sciences

Original papers:

(SUBJAREA(AGRI OR BIOC OR IMMU OR NEUR OR PHAR) AND (LIMIT-TO (DOCTYPE,"ar")))

Review papers:

(SUBJAREA(AGRI OR BIOC OR IMMU OR NEUR OR PHAR) AND (LIMIT-TO (DOCTYPE,"re")))