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How Scratch-and-Sniff Books Encode Smell Across Development

Jas Brooks [1], **Natalia Kucirkova** [2,3,*] **and Charles Spence** [4]

[1] Department of Electrical Engineering & Computer Science, Massachusetts Institute of Technology, 50 Vassar Street, Cambridge, MA 02139, USA

[2] The Norwegian Centre for Learning Environment, University of Stavanger, Stavanger 4320, Norway

[3] The Open University, Walton Hall, Kents Hill, Milton Keynes MK7 6AA, UK

[4] Crossmodal Research Laboratory, Department of Experimental Psychology, Life and Mind Building, University of Oxford, Oxford OX1 3PS, UK

[*]Corresponding author; e-mail: natalia.kucirkova@uis.no

ORCID iDs: Brooks: 0000-0002-6142-0346; Kucirkova: 0000-0002-2805-1745; Spence: 0000-0003-2111-072X

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Abstract

Scratch-and-sniff books combine olfactory cues with textual and visual narratives thus offering multisensory reading experiences. Despite their popularity since their emergence in the 1970s, these books have received little scholarly attention, particularly regarding their cognitive and developmental relevance. This paper presents a mixed-methods analysis of 334 scratch-and-sniff books, investigating how smell content varies by target age, conceptual complexity, and linguistic framing. Quantitative analyses reveal systematic differences in smell types, labelling strategies, and descriptive complexity depending on target readership age. Books targeted at younger readers tend to feature simple, explicitly labelled smells (e.g., "apple", "chocolate"), while those books targeting an older audience rely more on implicit references, humour, and/or socially transgressive smells (e.g., "fart", "smelly feet"). Qualitative readings show how olfactory cues are embedded in broader narrative structures that support inferencing, emotional resonance, and social norm acquisition. We argue that scratch-and-sniff books may be designed to use smell not only with the intention to entertain, but also to prompt crossmodal mapping, encourage inferential reasoning, and scaffold early engagements with sensory and social meaning. These findings indicate that scratch-and-sniff books systematically adapt their olfactory content and linguistic framing to developmental stages, suggesting that smell may serve not only to entertain, but also to scaffold emerging sensory, cognitive, and social capacities in early reading.

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books, developmental psychology, olfaction, reading, scent, scratch-and-sniff

1. Introduction

Scratch-and-sniff books represent a little-known but compelling domain for understanding how olfactory information is integrated into reading experiences. Among these, scratch-and-sniff books are the most prevalent, first introduced in the 1970s as a novelty in children's publishing. These books use microencapsulated fragrance oils that release a smell when scratched, typically aligning olfactory stimuli with textual or visual elements. Over time, they have expanded beyond early childhood audiences, engaging readers across a range of ages and literary genres.

Beyond their interactive appeal, books augmented with scratch-and-sniff function as cultural artifacts: they reflect societal trends, developmental expectations, and shifting sensory-linguistic norms. Yet, despite the popularity of scratch-and-sniff books, we are not aware of any academic research that has systematically examined their characteristics, history, or patterns of olfactory presentation across target readership ages. This constitutes a notable research gap, particularly given that early reading is increasingly understood as a multisensory process, and studies suggest that integrating sensory modalities (including smell) into early childhood resources can enhance engagement, memory, and concept formation (Kucirkova and Tosun, 2024; Shams and Seitz, 2008). As such, examining how smell is represented in books offers a valuable entry point into understanding its potential role in children's cognitive and linguistic development.

In this study, we present the first large-scale, systematic analysis of scratch-and-sniff books. Drawing on a corpus of 334 analysed titles (out of 407 published titles), we investigate how these books may be designed to present olfactory content in ways that reflect developmental and linguistic considerations. Our analysis focuses on three dimensions: we (1) examine which smells are most commonly featured and how their distribution varies by target age group; (2) analyse how the conceptual complexity of odour subjects differs between books for younger and older readers, including the role of implicit *versus* explicit descriptions; and (3) explore how the conceptual complexity of smell-related text correlates with the presence and structure of associated descriptions and textual cues.

2. Theoretical Framework for the Study

This study builds on frameworks in lexical quality theory (Perfetti, 2007), text complexity modelling (Montag, 2019; Nation *et al*., 2022), and multisensory learning (Shams and Seitz, 2008), extending them into the less explored domain of "olfactory literacy" (Kucirkova, 2024). Prior research has shown that olfactory language and categorization are shaped by cultural, linguistic, and ecological factors (Majid, 2021), and that children's ability to evaluate and describe odours becomes more differentiated with age (Valentin and Chanquoy, 2012). These studies provide important insights into olfactory development, drawing on experimental or task-based data. To complement this literature, we offer an empirical, corpus-level analysis of how books use smell-related content in ways that align with demographic targeting, developmental changes in olfactory preferences and identity, as well as increasing linguistic complexity. In particular, we trace how scratch-and-sniff books shift from reinforcing concrete object associations in early childhood to fostering more inferential, evaluative, and symbolic expressions that might be supporting in children's later developmental stages.

More broadly, this work contributes to ongoing efforts to connect research on olfaction in early childhood literacy studies with cognitive and developmental psychology. By examining a culturally embedded medium designed explicitly for different age groups, we show how children's encounters with smell are shaped not only by environmental influences, but also by resources that follow a narrative framing and linguistic structure. We aim to illustrate how olfactory cognition (often overlooked due to its methodological challenges) can be studied meaningfully through ecologically valid media like smell-enhanced books. In doing so, we propose that smell-enhanced literature offers a novel, data-rich resource for studying the ways in which sensory categories are portrayed, designed for and valued across one's lifespan.

2.1. Background

2.1.1. Smell-enhanced books in Multisensory and Developmental Contexts

Smell-enhanced books provide an example of a multisensory approach to design that augments visual content with non-visual stimuli such as smell, promoting the engagement of multiple senses: not only the so-called "higher" senses of vision and hearing, but also taste, touch, smell, and proprioception in everyday interactions (Mueller, 2019). Spence *et al*. (2024) conducted a historical narrative review and systematic database search to examine how scratch-and-sniff books enhance storytelling and engage readers. Their findings indicate that these books primarily target children, contrasting with the use of smell in other media aimed at adults. Beyond such conceptual and historical analyses, empirical studies examining how these books shape reading behaviours, memory encoding, or language acquisition remain limited.

One of the few empirical studies in this domain was reported by Kucirkova and Jensen (2023), who specifically examined how parents and children interacted with scratch-and-sniff books in the home environment. Their findings suggest that adults and children exhibit distinct patterns of engagement, with smell-enhanced features eliciting higher affective and behavioural engagement. These results align with broader research showing that olfactory stimuli can trigger strong associative learning and emotional responses (Herz and Engen, 1996).

Beyond engagement, the linguistic complexity of scratch-and-sniff books is another area that has yet to be explored. These books come in various formats, lengths, and textual structures, yet little research has examined how their word choice, sentence complexity, or integration of olfactory descriptions relate to learning outcomes or non-olfaction enhanced books. The content of a book (specifically the words used and the complexity of its sentences) is an important indicator of its learning potential. In this study, we focus on word length as an indicator of conceptual complexity and an important quality marker of books' content.

2.1.2. The Importance of Linguistic Complexity for Learning

Research suggests that text difficulty (along with book length), measured by grammatical complexity and vocabulary choice, influence children's reading comprehension and, thus, learning outcomes (Nation *et al*., 2022). Sentence complexity, in particular, has been shown to indirectly impact children's learning of complex sentences (Montag, 2019). While text complexity is well-studied in conventional reading materials, how these principles apply to smell-enhanced books remains unclear. If smell-enhanced books incorporate rich, descriptive language to convey olfactory experiences, they may serve as a scaffold for developing children's vocabulary and syntactic comprehension. Conversely, if they favour simplistic phrasing to accommodate interactivity, their linguistic contribution may be limited despite their multisensory engagement.

This relationship appears to be consistent across languages and cultural contexts. For example, Muranaka-Vuletich (2017) found that narrative type and participant age influence text length, cohesion, and sentence complexity. The study involved 30 monolingual Japanese speakers across three age groups (4-5 years, 8-9 years, and adults), who narrated stories using two elicitation tasks. The findings indicated that text length and cohesion improve with age, reflecting the development of cohesive devices. Inspired by these results, we included book length as an important variable for analysis in our study.

As for linguistic complexity, Zhao *et al*. (2022) analysed the linguistic complexity of 29 picture books used in a Chinese early English as a Foreign Language program, using CLAN software to assess alignment with expert grade-level judgments. Seven of 11 linguistic indices showed significant differences across levels, with vocabulary and syntactic complexity increasing in line with expert assessments. The findings suggest that child language development indices can reliably estimate text complexity. A similar approach could be used to assess smell-enhanced books. Similarly, Stavans and Zadunaisky-Ehrlich's (2023) study examined descriptive texts by 283 Hebrew-speaking Israeli children (grades 2–5) through writing and dictation tasks. The findings showed that text length increases and structural quality improve with age, with high-quality structures emerging by the third grade. In second grade, syntactic lexical ability influences text structure in written texts, partly *via* text length. By fifth grade, reading ability affects text structure in dictated texts, independent of text length. This raises a critical question for smell-enhanced books: do olfactory descriptions follow a developmental trajectory like other forms of descriptive language? If older children are more adept at processing longer and more structured descriptions, scratch-and-sniff books aimed at older children may incorporate more elaborate olfactory language. However, if these books prioritize accessibility across age groups, they may remain linguistically simple despite expanding in length. In other words, the question remains as to whether books aimed at older children feature more intricate olfactory descriptions, reflecting increased linguistic demands, or whether the integration of smell leads to a simplification of text, keeping language accessible regardless of intended age group. This was a sub-question we investigated in our study.

Of course, age range recommendations for books are not rigid boundaries but rather suggestive guidelines. A book recommended for ages "4–8 years" may also appeal to children slightly outside this range. Similarly, broader age categories, such as "3 and older", are more open-ended, with interest gradually declining as the reader's age diverges from the specified range. However, as children transition into preschool and early school years, both the length and complexity of the books they encounter typically increase, as evidenced by library acquisition patterns (Carver and Leibert, 1995). Smell-enhanced books often straddle multiple age groups, making it unclear whether their text complexity aligns with conventional reading level progressions. The key question remains whether scratch-and-sniff books aimed at older readers introduce more complex language, or whether their interactive nature keeps linguistic complexity low regardless of target age.

2.2. Guiding Analytical Frameworks

This study builds on two central areas of prior research: (1) lexical and linguistic complexity models of reading development, and (2) multisensory and olfactory cognition frameworks, which consider how smell supports learning, memory, and early concept formation.

2.2.1. Lexical Complexity and Learning from Text

Research in developmental and literacy studies has long emphasized that early reading comprehension depends not only on adult support but also on the linguistic structure of texts. For children under the age of eight years, shared reading with an experienced adult offers critical scaffolding: modelling sound-symbol correspondences, tracing letters, and co-constructing meaning (Barnes and Puccioni, 2017; Noble *et al*., 2019; Ruiz-Eugenio *et al*., 2023). Such interactions are especially valuable when paired with texts that contain syntactically and semantically rich content.

These insights align with the lexical quality hypothesis (Perfetti, 2007), which posits that proficient reading depends on well-specified form-meaning mappings in the mental lexicon. Texts with more complex vocabulary may better support the development of high-quality lexical representations, particularly when they challenge readers to navigate multiple cues for meaning.

The lexical quality hypothesis dovetails with text complexity models, which emphasize vocabulary richness, syntactic structure, and conceptual demand as key predictors of reader comprehension and learning outcomes (Montag, 2019; Nation *et al*., 2022). In conventional picture books, these variables often map onto developmental trajectories: younger readers are offered simpler syntax and concrete words, while books for older children increasingly feature abstract and grammatically intricate language (Stavans and Zadunaisky-Ehrlich, 2023; Zhao *et al*., 2022). These developmental patterns are relevant to the study of scratch-and-sniff books, particularly to investigate whether and how such books contribute to literacy through their descriptive content and interactive elements.

To operationalize these constructs in the current study, we draw on findings by Lewis and Frank (2016), who empirically demonstrated that word length reliably reflects conceptual complexity across languages. In a series of experiments, they found that longer words tend to describe more complex concepts, and this association remains robust even when controlling for frequency, imageability, and concreteness of the words. The approach provides a theoretically grounded and empirically validated method for estimating conceptual complexity in the absence of full semantic parsing. We adopt this approach to investigate whether olfactory subjects and its surrounding descriptions and textual cues increase in complexity across books targeting older

readers, thereby reflecting developmental shifts in linguistic and inferential capacities.

2.2.2. Multisensory Cognition and the Role of Smell

Complementing this linguistic lens, we draw from multisensory learning frameworks, which suggest that engaging multiple sensory modalities can enhance learning outcomes by activating distinct neural pathways and reinforcing memory traces (Shams and Seitz, 2008; Talsma *et al*., 2010). These mechanisms can yield more durable memory traces and greater attentional engagement than unisensory input alone (Gori, 2015). Importantly, the benefits of multisensory input appear to be especially pronounced in early childhood, when sensory systems are still developing and integration relies heavily on redundant, temporally and spatially aligned cues.

The learning benefits of multisensory stimulation are yet to be determined; a recent study showed that children's letter knowledge was not increased in an experimental condition that contained multiple sensory modalities (visual, auditory, tactile, and gross-motor kinaesthetic) as opposed to auditory and visual only condition (Park *et al*., 2025). Dionne-Dostie *et al*. (2015) emphasize that multisensory stimulation in infancy and early childhood can heighten attention and support the emergence of cognitive abilities but does not specify how these modalities could complement each other and for which developmental outcomes. There is little prior literature that explores how smell-enhanced books (by aligning olfactory, visual, and linguistic input) may support perceptual and conceptual development, particularly when cues are semantically meaningful and contextually grounded.

We also draw from research in developmental olfactory cognition, particularly around the acquisition of odour hedonics: the subjective evaluation of smells as pleasant or unpleasant, shaped by individual experience, cultural context, and emotional associations (Poncelet *et al*., 2010; Rinck *et al*., 2011). Studies suggest that children's odour preferences begin to evolve meaningfully between ages three and five years of age, coinciding with emerging abilities to label and semantically categorize smells (Cameron, 2018). Bensafi *et al*. (2007) found that verbal cues can modulate five-year-old children's hedonic ratings of otherwise neutral odours, indicating that language begins to exert a top-down influence on odour evaluation early in development. Similarly, Poncelet *et al*. (2010) found that both children and older adults (groups with either underdeveloped or degraded access to odour semantics) relied more on the physicochemical properties of smells, while teenagers and young adults modulated their preferences based more on semantic associations and culturally learned meanings. It is well-documented that smell identification changes with age: in an early study with 1955 five to ninety-nine-olds, Doty *et al*. (1984) found that best smell identification occurs between 30–50-year-olds.

These results have been replicated by Sorokowska *et al*. (2015) and they also found that older children have higher olfactory abilities than younger children. There is also a growing body of evidence showing that diverse olfactory environment are related to the variation in children's olfactory abilities and odour awareness (Martinec Nováková *et al*., 2018a), although preliminary data suggest that there are also some consistencies in children's hedonic perceptions of odours across 18 countries (Oleszkiewicz *et al*., 2022).

Beyond hedonic development, olfactory perception itself is malleable across childhood: exposure shapes odour discrimination, identification, and metacognitive awareness (Martinec Nováková *et al*., 2018b; Rinck *et al*., 2011; Zhang *et al*., 2017). Neuroscientific and behavioural research further shows that olfactory circuits remain highly experience-dependent (Coppola and Reisert, 2023), and even short-term training can enhance children's olfactory awareness and metacognitive monitoring (Oleszkiewicz *et al*., 2025). This aligns olfaction with broader models of perceptual attunement in development, providing a conceptual parallel to well-documented tuning processes in speech perception.

This developmental trajectory reflects a transition from affective and sensory-based odour judgments toward more abstract, culturally structured olfactory meanings. Majid (2021) built on this literature by framing the well-documented olfactory-verbal gap (e.g., Engen, 1991) as culturally variable rather than universal. While Western languages often lack rich smell vocabularies, other linguistic communities (particularly those in smell-rich ecological contexts) develop nuanced lexicons and cultural practices for smell-based communication. These findings highlight that olfactory language development is shaped not just by neurobiological constraints, but also by language, culture, and the olfactory environment.

Although Piaget's (1952) cognitive developmental stages do not explicitly discuss olfaction, and have been critiqued for their limited generalizability across domains and contexts (Lourenço and Machado, 1996), we hypothesize (based on his broader framework) that children in the preoperational stage (approx. 2–7 years) may process smell primarily through direct object associations (e.g., "apple smells like apple"), whereas children in the concrete operational stage (approx. 7–12 years) begin to describe and compare smells based on categorical properties or evaluative functions (e.g., "this smells sweet" or "this smells like something rotten"). This developmental progression is supported by empirical work from Valentin and Chanquoy (2012), who found that older children (ages 10–11 years) were more accurate at naming and categorizing odours than younger children (ages 6–7 years), and that verbal labels facilitated better categorization. Their findings suggest that as children mature, their olfactory representations become increasingly abstract and semantically structured, transitioning from simple object-based associations toward a more

conceptually organized odour lexicon. This shift (from perceptual to semantic processing) provides a cognitive foundation for investigating whether the design of scratch-and-sniff books evolves in the books' use of smell, from reinforcing concrete object links to supporting more inference-based or category-based interpretations.

In this study, by drawing on these multisensory and developmental frameworks, we assess how smell descriptions in books vary across age groups: not just in terms of vocabulary length or syntactic complexity, but also in the types of odours depicted and the conceptual meanings they may carry. This dual emphasis on language and olfaction allows us to examine how children's reading of scratch-and-sniff books might contribute to scaffolding both cognitive development and sensory acculturation.

2.3. Aims, Objectives, and Hypotheses

This study investigates how scratch-and-sniff books present olfactory stimuli across different stages of human development, focusing on the linguistic characteristics and smell content of books targeted at varying age groups. Rather than analysing reader interactions or conducting experimental manipulations, we take an observational, theory-driven approach, systematically examining how smell is embedded in the books themselves: which odours are featured, how they are described, how these descriptions change with the intended readership's age, and how readers are textually cued to interact with the odours. In doing so, we explore how the formal properties of smell-enhanced books may reflect or even scaffold known developmental changes in sensory perception, language acquisition, and symbolic reasoning. We explore three core research questions:

(RQ1) What are the primary smells featured in scratch and sniff books, and how do these differ by target reader age group?

(RQ2) How does the conceptual complexity of odour subjects vary between books for younger *versus* older audiences, and what role do implicit *versus* explicit descriptions play in this variation?

(RQ3) How does the conceptual complexity of odour subjects correlate with the presence and complexity of associated textual cues?

From these questions, we derive four hypotheses:

(H1) Olfactory exposure hypothesis: Children's smell preferences may become increasingly shaped by the odours they encounter in their cultural and

everyday environments.[1] As outlined earlier, olfactory perception is malleable across childhood, with exposure influencing discrimination, identification, and odour meaning. Thus, we expect books for younger children to highlight familiar, comforting, food-based smells, and books for older readers may introduce more abstract, complex, or socially meaningful odours.

(H2) Cognitive association hypothesis: We hypothesize that specific smells align with developmental milestones in verbal and conceptual ability. Younger children may describe smells through direct object associations (e.g., "banana smells like banana"), while older children begin to use abstract, evaluative, or category-based labels (e.g., "this smells fresh" or "this smells gross"). This shift mirrors Piaget's stages of preoperational to concrete operational thought (Piaget, 1952), in which children move from symbolic association to more systematic categorization. Empirical evidence supports this trajectory: children initially struggle to name and describe odours (Engen, 1991) but later become more proficient in hedonic and categorical judgments (Valentin and Chanquoy, 2012). However, as argued by Majid (2021), this progression is not universal but shaped by linguistic and cultural environments, suggesting that olfactory labelling may develop differently across reading audiences and cultural contexts.

(H3) Linguistic complexity hypothesis: Books aimed at older children and adults will feature longer and more conceptually complex descriptions, consistent with broader models of age-related increases in text complexity.

(H4) Implicit *vs.* explicit smell description hypothesis: We expect younger-targeted books to use explicit textual cues (e.g., "Scratch here to smell the cake"), whereas books for older readers will rely more on implicit language and narrative context to signal smell, reflecting growing inferential and linguistic capacity.

3. Methods

We began by compiling a comprehensive database of scratch-and-sniff books from bibliographic sources, publisher catalogues, and second-hand retailer listings. Physical or digital copies were obtained for as many titles as possible to ensure direct access to the materials. This was essential for analysing not

[1] While familiarity often supports preference, this may not be universally the case: for example, trigeminal odours (such as pungent smells) could remain aversive.

only the presence of olfactory features but also how smells were linguistically and visually integrated into each book's narrative structure. Titles for which no full copy could be obtained were excluded from further analysis. This approach ensured that all included books could be systematically assessed for smell content, cue structure, and language use: core elements of the study.

3.1. Book Corpus Compilation and Selection Criteria

Book compilation followed systematic review principles based on the PRISMA statement (Page *et al*., 2021), typically used in meta-analyses and systematic literature reviews. The initial dataset was drawn from the openly accessible database compiled by Spence *et al*. (2024), which provided a foundational list of titles. This was supplemented with data from Brooks (2020) who had documented the smells included in a subset of books. To expand coverage further, we conducted a supplementary search on WorldCat.org, targeting books listed under the categories "Scented books" and the French-language equivalent "Livres parfumés." This multilingual and multi-source approach helped ensure broader coverage and reduced dataset bias toward English-language or U.S.-based publications.

Titles were compiled between December 2023 and January 2024. The WorldCat search for "Scented books" returned 396 entries, while "Livres parfumés" yielded 208, including 142 previously unlisted titles. These additions expanded the dataset to include more books targeting adults and a small number of books in other languages (notably French, Serbian, Vietnamese, and Chinese). Artworks in book-like forms, such as Islam Aly's *Concoctions* series, were excluded to maintain a focus on commercially published books intended for general readership.

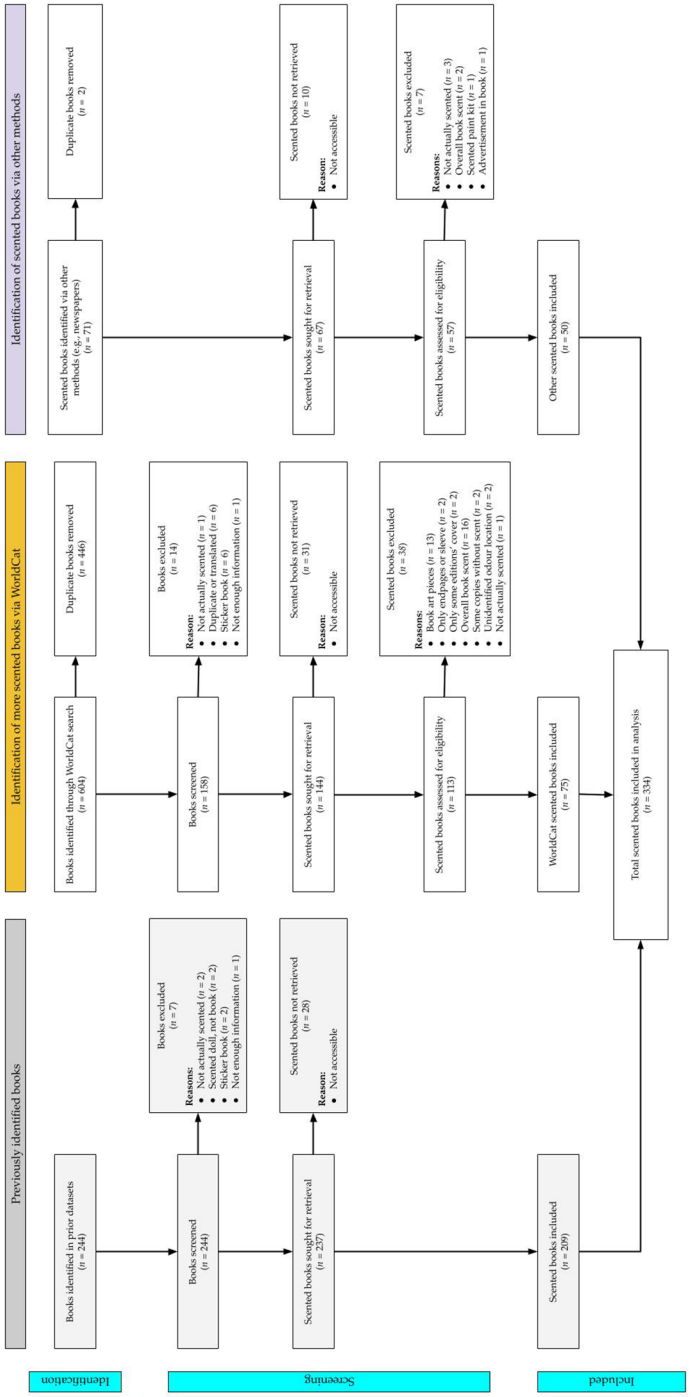
The final dataset comprised 407 unique smell-enhanced books, of which 334 were reviewed in detail to evaluate their embedded olfactory elements. These books formed the basis of the analyses presented in this paper (see Figure 1 for a PRISMA-style flow diagram of the selection process).

3.2. Olfactory and Multisensory Feature Annotation

For each book, we documented core metadata, including the total page count, page layout (i.e., whether the book opened on a left- or right-hand page), and the presence of any smell usage instructions. Every distinct odour in the book

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Figure 1. PRISMA-style flow diagram illustrating the selection process for smell-enhanced books included in this study. Books were identified through prior datasets, WorldCat searches, and other sources such as newspapers and catalogues. After screening and retrieval attempts, 334 books were included for detailed evaluation of embedded olfactory elements. Note: not all books were used in every analysis; see individual results sections for final sample sizes per analysis.


Identification
Screening
Included
Previously identified books
Identification of more scented books via WorldCat
Identification of scented books via other methods
Books identified in prior datasets (n = 244)
Books screened (n = 244)
Books excluded (n = 7)
Reasons:
Not actually scented (n = 2)
Scented ink, not book (n = 2)
Sister book (n = 2)
Not enough information (n = 1)
Scented books sought for retrieval (n = 237)
Scented books not retrieved (n = 28)
Reason:
Not accessible
Scented books included (n = 209)
Books identified through WorldCat search (n = 604)
Duplicate books removed (n = 446)
Books screened (n = 158)
Books excluded (n = 14)
Reason:
Not actually scented (n = 1)
Duplicate or translated (n = 6)
Sister book (n = 6)
Not enough information (n = 1)
Scented books sought for retrieval (n = 144)
Scented books not retrieved (n = 31)
Reason:
Not accessible
Scented books assessed for eligibility (n = 113)
Scented books excluded (n = 38)
Reasons:
Book art pieces (n = 13)
Only endpages or sleeve (n = 2)
Only some editions' cover (n = 2)
Overall book scent (n = 16)
Scent on cover, not whole book (n = 2)
Unidentified odour location (n = 2)
Not actually scented (n = 1)
WorldCat scented books included (n = 75)
Scented books identified via other methods (e.g., newspapers) (n = 71)
Duplicate books removed (n = 2)
Scented books sought for retrieval (n = 67)
Scented books not retrieved (n = 10)
Reason:
Not accessible
Scented books assessed for eligibility (n = 57)
Scented books excluded (n = 7)
Reasons:
Not actually scented (n = 3)
Overall book scent (n = 2)
Scented paint kit (n = 1)
Advertisement in book (n = 1)
Other scented books included (n = 50)
Total scented books included in analysis (n = 334)

was catalogued with its corresponding page number and application method (e.g., microencapsulated sticker, screen-printed patch).

For each odour, we identified its associated subject (the object or concept linked to the smell) using the most specific information available. When a subject was explicitly named in the text (e.g., "banana", "dirty socks"), we transcribed the word directly. When no textual label was present, we inferred the subject from visual and narrative context (e.g., illustrations). If neither textual nor visual elements provided a reliable cue, the entry was excluded from analyses involving odour subjects.

We also recorded any in-text descriptors associated with the odour, typically adjectives or short phrases conveying its sensory qualities (e.g., delicious, smelly, sweet, and warm).

In addition, we annotated all accompanying multimodal cues, defined as any elements that signalled the presence of a smell or prompted reader interaction. These cues included:

- Textual cues (e.g., "Scratch and sniff here!"),
- Visual cues (e.g., arrows, glows, or characters visibly interacting with the odour subject),
- Tactile cues (e.g., raised stickers), and
- Auditory cues, such as sound modules embedded in the book that play relevant effects (e.g., a sniffing sound) when activated.

Textual prompts were transcribed verbatim, while non-verbal cues were described using a consistent terminology (e.g., "Sticker elevation" for raised tactile features). This coding enabled us to analyse not only the odours themselves and how they were described, but also the design strategies used to guide readers' engagement across sensory modalities, with the present study focusing specifically on textual cues.

Finally, we sought to classify the function of each odour using Banes' taxonomy, originally developed for analysing scent in stage performances (Banes, 2010). Banes identified seven categories for scent use: (A) to illustrate; (B) to evoke a mood or ambience; (C) to complement or contrast the audiovisual signs; (D) to summon specific memories; (E) to frame as ritual; (F) to serve as a distancing device; and (G) to be unrecognizable. While this framework was not designed for printed media, it offered a useful starting point for describing how smell is employed. We applied these categories flexibly, acknowledging overlap and ambiguity in some cases (e.g., whether holiday-related scents like oranges illustrate, evoke ritual, and/or evoke mood). As an exploratory first step, this classification provides a foundation for future work to refine and validate more rigorous coding schemes for scent function in literary media.

The full annotation was conducted by the first author, who had direct physical access to the complete scratch-and-sniff collection (much of which is unavailable in digitized form) and who holds extensive expertise in olfactory media research. This single-annotator approach ensured consistency in interpretive judgements across the dataset.

3.3. Estimating Target Readership Age Distributions

To model the likely age readership for each book, we used a weighted Gaussian kernel density approach based on metadata from multiple sources. We parsed target age information from explicit book annotations as well as listings on platforms such as WorldCat, Amazon, Walmart, and eBay. For each source that provided an age range, we generated a separate Gaussian distribution to represent the probable age readership implied by that source. The standard deviation of each distribution was scaled based on the width of the age range, such that narrower age bands produced sharper peaks (e.g., "ages 4–5 years") and broader bands yielded flatter, more diffuse distributions (e.g., "ages 3–12 years").

These source-specific distributions were then aggregated into a composite age distribution for each book. A weighted average of the distributions was computed, assigning greater weight to Amazon data when the listing note indicated that the age range reflected customer-derived input: under the rationale that these data more closely capture real-world readership patterns than publisher or library classifications.

In addition to books with numeric age ranges, many titles used categorical descriptors such as "young readers" or "teen." These were mapped to estimated numeric age ranges based on publisher conventions, marketplace norms, and developmental literature (see Table 1), allowing for consistent treatment in the distributional model.

For open-ended age ranges (e.g., "3 years and up"), we applied a tapering mechanism to gradually reduce the influence of the kernel at higher ages. This adjustment reflects the fact that while such books may be accessible to older readers, interest typically declines with age. The final result was a smoothed, probabilistic age distribution for each book, which captures the flexible and overlapping nature of book readership while enabling systematic, age-sensitive comparisons across the corpus. See Figure 2 for examples of the resulting target readership age distribution of several books.

3.4. Data Analysis Overview

We used a combination of natural language processing (NLP), statistical modelling, and peak-based detection techniques to examine how olfactory content in scratch-and-sniff books varies across age groups. The analysis proceeded in two phases. First, we identified which smells were most associated with dif-

Table 1.
Mapping of target audience categories to estimated age ranges, derived from explicit book classifications, online retailer categorizations, and content analysis

Target audience label	Estimated age range (years)
Toddler	1–3
Preschool	3–5
Young children	2–5
Child	3–9
Juvenile audience	3–12
Young readers	5–10
Teen	13–19
Rated teen+	13–20
Young adult(s)	18–24
Adult(s)	21–26

These mappings were used to normalize and analyse age-related trends in smell-enhanced books.

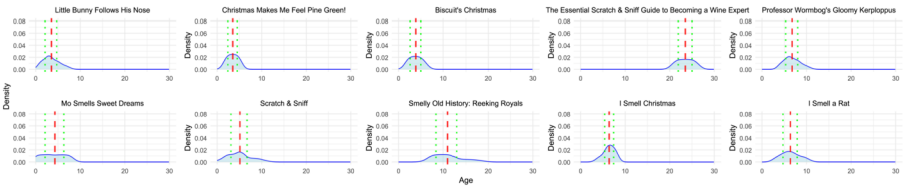


Figure 2. Estimated target readership age distributions for 10 randomly sampled scratch-and-sniff books. Each subplot displays a kernel density estimate of the target age range, with the book's name noted above. Distributions are truncated at age 30 to avoid distortion from the broad and sparsely populated adult category. Red dashed lines indicate the mean, while the green dotted lines indicate the lower and upper quartiles.

ferent developmental stages using age-weighted frequency distributions and multiple peak-based metrics. Second, we evaluated the conceptual complexity of odour-related content (such as subject terms and descriptions) and examined how these features varied as a function of book-level metadata, including target readership age and publication date.

3.4.1. Identifying Developmentally Salient Smells

To identify which smells are most salient across developmental stages, we combined natural language processing with age-weighted statistical modelling. This analysis aimed to capture both the most prevalent odours across target age groups and those that were particularly distinctive for a specific developmental window.

We first applied standard natural language processing techniques (tokenization, lemmatization, and stop-word removal) to all smell-related terms, includ-

Table 2.
Developmentally grounded age groups used in the analysis, including corresponding age ranges and brief descriptions of relevant cognitive, linguistic, and social milestones

Age group label	Age range (years)	Developmental stage description
Infancy and toddlerhood	0–3	Early sensory exploration; minimal linguistic capacity
Preschool age	3–5	Expanding vocabulary; beginning symbolic play and simple labelling
Early childhood	5–8	Developing categorization skills; early inferential thinking
Middle childhood	8–12	Emerging abstract reasoning; humour and social norms become salient
Adolescence	12–18	Identity formation; greater symbolic and evaluative reasoning
Adulthood	18–30	Mature narrative comprehension; culturally shaped preferences

ing odour subject labels (e.g., "banana") and in-text descriptors (e.g., "sweet", "warm"). Compound terms were simplified when necessary (e.g., removing "tree" from "pine tree") to focus on the core olfactory referent.

To estimate age associations for each smell, we aggregated the target readership age distributions of all books in which that smell appeared. To prevent overrepresentation by books that heavily emphasize a particular smell (e.g., books dominated by fart-related content), each book contributed only one instance per smell to the aggregate distribution. This normalization step reflects the fact that smells in books are typically presented as part of a collection rather than in isolation.

We then used two complementary approaches to identify the most salient smells for each age bracket. First, we calculated the area under the curve (AUC) for each smell's age distribution, capturing cumulative presence across the age range. Second, we applied a tallest peak criterion, retaining only smells whose single most prominent association occurred within the target age window. Each approach captures a different aspect of age-related salience: broad prevalence and strongest developmental specificity, respectively.

We conducted these analyses across six developmentally relevant age groups, summarized in Table 2. These brackets were designed to align with known shifts in sensory perception, linguistic complexity, and conceptual reasoning. Because age metadata in children's books is typically more specific than in books targeting general adult audiences, our peak-based analyses are more sensitive and informative for younger age groups. In contrast, adult-

targeted books tend to produce flatter age distributions, limiting the interpretability of their peaks in this context.

3.4.2. Modelling the Relationship between Age and Olfactory Language Use

To examine how the complexity and structure of smell-related language varies with book characteristics, we conducted a series of generalized linear and mixed-effects models. Our models used three key predictors: the Mean Target Age (i.e., the average of a book's estimated age distribution, reflecting its central intended readership); the Interquartile Age Range (capturing how narrowly or broadly a book is targeted, based on the spread between the 25th and 75th percentiles of its age distribution); and the Book Age (measured as the number of years since publication, relative to 2025).

These predictors were used to model several dependent variables related to smell representation. First, we examined the presence or absence of olfactory descriptions and textual cues: binary outcomes analysed using binomial generalized linear mixed models (GLMMs) with complementary log-log links, appropriate for skewed distributions and rare events. Next, we assessed variation in the average length of odour subject length, using negative binomial GLMMs to account for overdispersion in count data. We then used gamma GLMMs with a log link to model variation in average word length of textual cues, which are strictly positive and right skewed. Finally, we analysed variation in the average length of descriptions using linear mixed models (LMMs), applied to log-transformed data to normalize residuals.

All models included the book as a random intercept, indexed by a unique identifier (Book ID) assigned to each publication, to account for multiple observations within the same title. Mixed-effects modelling allowed us to address the nested structure of the dataset (e.g., multiple odours per book) while enabling generalization across the corpus. Model assumptions were evaluated through diagnostic tests for residual deviation, overdispersion, and the influence of outliers, with results reported alongside each model.

4. Results

This section presents both descriptive and statistical analyses of our corpus of scratch-and-sniff books. We begin by examining age-related trends in smell content, exploring which smells appear most frequently across different developmental stages. We then turn to statistical models to analyse how the linguistic features of olfactory subjects, descriptions, and cues vary based on target reader age, book publication year, and phrase characteristics. Together, these analyses reveal meaningful shifts in how smell is represented and scaffolded for readers across the lifespan.

The comprehensive plot indicates that the most targeted age group is around 3–6 years of age. When focusing on the range representing 75% of the target

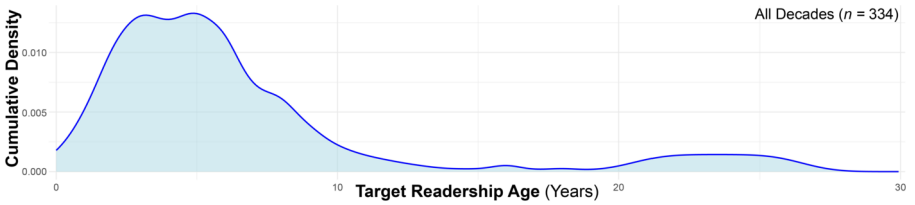


Figure 3. Distribution of estimated target readership age for all scratch-and-sniff books in the dataset. The density curve shows a strong peak around early childhood (approximate ages 2–6 years), indicating that most books are aimed at young children. A secondary plateau appears around adulthood, reflecting an increase in smell-enhanced books targeted at adult readers. Notably, there is a visible gap in books targeting the adolescent age range (approximate ages 12–18 years), suggesting an underutilization of olfactory media for teen audiences specifically.

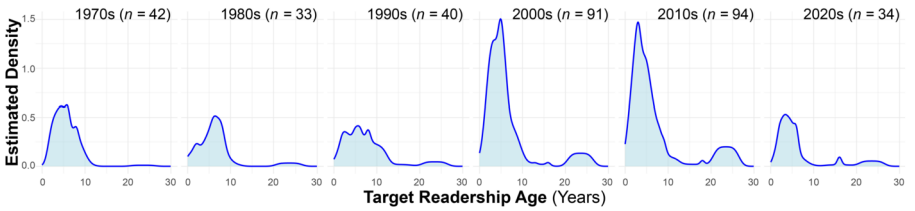


Figure 4. Kernel density plots of estimated target readership age for smell-enhanced books across decades from the 1970s (first scratch-and-sniff book published) to the 2020s (ongoing). Each panel displays the raw (unnormalized) density of target ages for books published in that decade, allowing comparison of both age distribution and publication volume over time. While early decades (1970s–1990s) predominantly focus on young children (ages 2–8 years), there is a clear increase in books aimed at adult readers (ages 18+ years) beginning in the 2000s. Across all decades, books targeting adolescents (ages 12–18 years) remain sparse.

readership and limiting the age to 0 through 18 years (since "Adults" spans a wide range and tends to be overrepresented), the range narrows down to 1.5 to 7.3 years old, peaking at 2.7 years old.

Figures 3 & 4 reveals a notable shift in the publication landscape: while most smell-enhanced books have historically targeted early childhood (ages 2–7 years), recent decades show a growing number of titles aimed at adults. At the same time, there remains a striking underrepresentation of books specifically geared toward adolescents, suggesting a missed opportunity in leveraging olfactory media for teenage readers.

4.1. Functional Roles of Smells

Our analysis revealed that the most common function for categorized smells in the dataset ($n = 2048$) was illustrative (Category A), accounting for 83.3%. These smells were directly tied to objects or characters mentioned in the book, often reinforcing referential understanding. The next most frequent category was ritualistic use (Category E, 16.1%), often tied to culturally symbolic

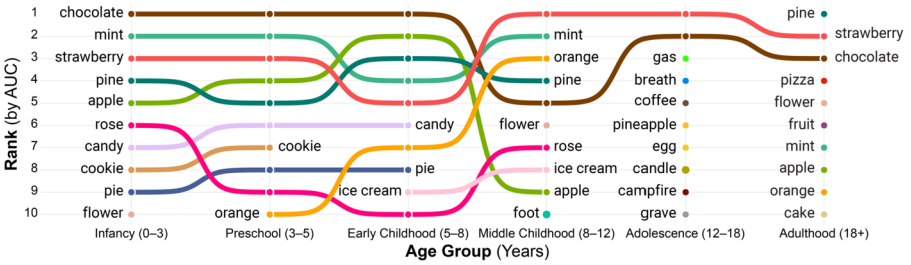


Figure 5. Rank flow of the top 10 most frequently included smells across age groups, based on area under the curve (AUC) of each smell's age distribution. Smells are ranked within each age group by the cumulative AUC of their presence across books within that developmental stage.

contexts like holidays (e.g., Christmas). Smells used to evoke mood or ambience (Category B, 5.6%) and those that complement or contrast audiovisual signs (Category C, 4.2%) appeared in a smaller portion of the dataset. Rarely, smells were unrecognizable (Category G, 1.4%) or functioned as distancing devices (Category F, 0.7%). None of the smells in the current dataset were clearly classified as memory-summoning (Category D). As our classification was exploratory and occasionally ambiguous (particularly for entries linked to festive or seasonal contexts) the prevalence of Category E may be underestimated.

4.2. Descriptive Age-Smell Patterns

Per our analytical methodology, a figure and table were produced highlighting smells that are overall most common (Figure 5) and are most strongly associated to a single age group (Table 3).

In infancy and toddlerhood (0–3 years), books overwhelmingly feature comforting, familiar food-based smells: most notably chocolate, candy, apple, and strawberry. These smells are widely distributed across titles for this age range. A smaller subset of books includes less common food or natural smells, but their relative rarity may reflect the limited number of smells explicitly limited to this youngest age group, rather than a deliberate effort to introduce olfactory variety during infancy.

During the preschool age (3–5 years), the dominance of sweet and fruity smells continues. Bakery smells and classic treats remain prevalent, and chocolate reaches its sharpest peak around 4.9 years, confirming its strong association with this stage. While other smells like banana, flower, cookie, and rose also peak within this range, they appear in fewer books overall, suggesting more specialized thematic deployment rather than broad usage.

In early childhood (5–8 years), the variety of frequently used smells expands. While food smells such as chocolate, apple, and strawberry remain frequent, more diverse categories emerge, including peppermint, cinnamon,

Table 3.
Top ten odours most distinctly associated with each age group (age in years), identified by the tallest single peak within the developmental window

Rank	Infancy (0–3)	Preschool (3–5)	Early childhood (5–8)	Middle childhood (8–12)	Adolescence (12–18)	Adulthood (18–30)
1	lavender (0.33, 2.9)	chocolate (1.4, 4.9)	apple (1.1, 5.7)	foot (0.18, 9.0)	gas (0.092, 16.0)	caramel (0.067)
2	lollipop (0.23, 2.9)	strawberry (1.0, 4.8)	pine (0.99, 5.6)	clover (0.15, 8.0)	coffee, candle, grave, persimmon (0.079, 16.0)	wee (0.048)
3	perfume (0.22, 2.3)	mint (1.0, 4.9)	candy (0.91, 5.6)	sweet (0.11, 8.0)	Santa (0.014, 16.0)	central, horse, park, taxi (0.043)
4	green (0.18, 2.8)	cookie (0.72, 3.7)	orange (0.77, 5.8)	sock, campfire (0.080, 8.0)		garlic (0.041)
5	marshmallow (0.16, 2.9)	pie (0.71, 3.5)	ice cream (0.59, 5.2)			roast (0.037)
6	melon (0.13, 2.4)	rose (0.69, 3.4)	cinnamon (0.49, 5.6)			
7	fart (0.11, 2.1)	flower (0.59, 3.2)	lemon (0.48, 5.4)			
8	blue (0.092, 2.6)	Gingerbread (0.59, 4.6)	cherry (0.38, 5.8)			
9	dog (0.086, 2.0)	banana (0.54, 4.5)	peanut (0.34, 6.0)			
10	cat (0.08, 2.0)	cake (0.48, 4.8)	cheese (0.34, 5.0)			

Peak height and peak age highlight odours uniquely prominent at specific developmental stages.

lemon, peanut, and orange. The presence of peanut and cinnamon signals a move beyond purely sweet or edible odours toward savoury and spice-based smells. Overall, this stage marks a transitional period, with smell variety increasing and smell content becoming more differentiated.

A clear shift is observed in middle childhood (8–12 years). Sweet staples such as strawberry and chocolate remain common, but the emergence of "gross" or bodily smells becomes notable. Odours like smelly cheese, sock, and foot emerge, aligning with known developmental trends in social disgust and the growing appeal of transgressive humour during this period. These smells appear intentionally selected to provoke laughter, surprise, or mild disgust, supporting our hypothesis that books in this age group begin to engage readers in more evaluative and socially layered ways.

Though fewer books are explicitly targeted at adolescents (12–18 years), those that do show a marked thematic shift toward identity, mood, and real-world relevance. While food smells remain frequent (e.g., chocolate and strawberry), books for this group also introduce odours like coffee, gas, breath, candle, and grave. These smells are less about familiarity or novelty and more about emotional resonance, aesthetic symbolism, or personal identity, suggesting a conceptual and symbolic reframing of olfactory experiences.

In sum, the representation of smells in scratch-and-sniff books would appear to follow a developmentally meaningful arc: Infancy and Toddlerhood and Preschool Age are characterized by sweet, concrete, and comforting food-based odours; Early Childhood introduces nature and spice-based smells, indicating expanding olfactory categories; Middle Childhood engages with humour and disgust, reflecting growing social and evaluative capacities; and Adolescence sees a move toward more abstract, symbolic, or identity-linked smells.

4.3. Developmental Shifts in Odour Representation

To better understand how olfactory representation shifts across developmental stages, we built a series of mixed-effects models examining the relationship between target age and key linguistic features of smell content. These models test two hypotheses: that older-targeted books employ longer or more complex olfactory descriptions (H3), and that books for older readers are more likely to use implicit rather than explicit smell cues (H4). The following sections present our modelling results in detail.

4.3.1. Odour Subject Phrase Length (Negative Binomial GLMM)

To examine factors influencing the length of odour subject phrases (including compound words like "chocolate cake"), we fit a negative binomial generalized linear mixed model (GLMM) with a log link. This model was chosen due to overdispersion in the count data, where a standard Poisson model

would have underestimated variance. The outcome variable was the character length of the Odour.Subject field. We included Book ID as a random intercept to account for repeated observations across books ($N = 2118$ observations, $n = 333$ books). The model specification was as follows:

$$\begin{aligned}\log\left(E\left[\text{Odour Subject Length}_i\right]\right) &= \beta_0 + \beta_1 \cdot \text{Mean Target Age}_i + \beta_2 \cdot \text{Book Age}_i \\ &\quad + \beta_3 \cdot \text{Interquartile Age Range}_i + u_{\text{BookID}[i]}\end{aligned}$$

Where: β_0 is the intercept; $\beta_1, \beta_2, \beta_3$ are fixed-effect coefficients; $u_{\text{BookID[i]}}$ is the random intercept for each book; and a zero-inflation component π was modelled as constant.

The model revealed a significant positive effect of Mean Target Age ($B = 0.0071$, SE $= 0.0029$, $z = 2.44$, $p = 0.0147$), suggesting that books targeted at older readers contain longer odour-related phrases (and thus likely have higher conceptual complexity). However, Book Age ($B = 0.0013$, SE $= 0.0011$, $z = 1.22$, $p = 0.2244$) and Interquartile Age Range ($B = -0.0012$, SE $= 0.0059$, $z = -0.21$, $p = 0.8372$) were not significant predictors.

Model fit was acceptable (AIC $= 12067.8$; BIC $= 12107.4$; $\log L = -6026.9$), and the estimated dispersion parameter was 10.5. The random intercept variance across books was 0.0437 (SD $= 0.209$), indicating modest variability in odour subject phrase length across titles. The zero-inflation component was not significant ($B = -21.91$, SE $= 1401.72$, $p = 0.988$), suggesting no excess zeros beyond what the negative binomial distribution accounts for. Residual diagnostics indicated significant deviation from uniformity (Kolmogorov–Smirnov test: $p = 0$), though both the dispersion test ($p = 0.088$) and outlier test ($p = 0.623$) were non-significant. This points to some heteroscedasticity but, overall, the model provides a reasonable fit to the data.

4.3.2. Presence of Descriptions (Binomial GLMM)

To examine which factors predict the presence of olfactory descriptions in children's books, we fit a binomial GLMM using a complementary log-log link. This link function is appropriate when modelling binary outcomes where the probability of occurrence is low or skewed, as it accommodates asymmetry better than the logistic link. The model included Mean Target Age, Book Age, Interquartile Age Range, and Odour Subject Phrase Length as fixed effects. A random intercept for *Book ID* was included to account for repeated measures across books ($N = 2118$ observations, $n = 333$ books). The model is specified as:

$$\begin{aligned}\text{cloglog}\left(\Pr\left(Y_i = 1\right)\right) &= \beta_0 + \beta_1 \cdot \text{Mean Target Age}_i + \beta_2 \cdot \text{Book Age}_i \\ &\quad + \beta_3 \cdot \text{Interquartile Age Range}_i \\ &\quad + \beta_4 \cdot \text{Odour Subject Length}_i + u_{\text{BookID}[i]}\end{aligned}$$

Where: β_0 is the intercept; β_1, β_2, β_3 are fixed-effect coefficients; $u_{\text{BookID[i]}}$ is the random intercept for each book; and a zero-inflation component π was modelled as constant.

The model revealed a significant negative effect of Mean Target Age effect ($B = -0.0448$, SE $= 0.0172$, $z = -2.60$, $p = 0.009$), suggesting that books for older audiences are less likely to include explicit odour descriptions. Book Age had a positive effect ($B = 0.0171$, SE $= 0.0057$, $z = 3.00$, $p = 0.0027$), indicating that older books were more likely to contain descriptions. Neither Interquartile Age Range ($B = -0.0047$, $p = 0.884$) nor Odour Subject Phrase Length ($B = 0.0082$, $p = 0.372$) were significant predictors.

Model fit statistics were acceptable (AIC $=$ 2365.9; BIC $=$ 2399.9; $\log L = -1177.0$), and the random intercept variance across books was 1.563 (SD $=$ 1.25), indicating substantial between-book variability in the presence of descriptions. Residual diagnostics revealed significant deviation from uniformity (Kolmogorov–Smirnov test: $p = 0.00187$), suggesting mild heteroscedasticity, though dispersion ($p = 0.912$) and outlier ($p = 0.141$) tests were non-significant. These results suggest that while the model fits reasonably well, there may still be unexplained variance in how and why descriptions are included.

4.3.3. Variation in Description Length (LMM)

To examine which factors influence the average length of olfactory description phrases, we fit a linear mixed-effects model (LMM) to the log-transformed average phrase length. We used a log-transformation (log1p) to normalize the positively skewed distribution of description lengths and to accommodate zero-truncation (i.e., only books with at least one description were included; $N = 810$ observations, $n = 242$ books). Predictors included Mean Target Age, Book Age, Interquartile Age Range, and Odour Subject Phrase Length. A random intercept for Book ID was included to account for repeated measurements within books. The model is specified as:

$$\begin{aligned} Y_i = \beta_0 &+ \beta_1 \cdot \text{Mean Target Age}_i + \beta_2 \cdot \text{Book Age}_i \\ &+ \beta_3 \cdot \text{Interquartile Age Range}_i \\ &+ \beta_4 \cdot \text{Odour Subject Length}_i + u_{\text{BookID}[i]} \end{aligned}$$

Where: β_0 is the intercept; β_1, β_2, β_3, β_4 are fixed-effect coefficients; and $u_{\text{BookID[i]}}$ is the random intercept for each book.

None of the predictors were statistically significant, including Mean Target Age ($B = 0.0033$, $p = 0.157$), Book Age ($B = -0.0001$, $p = 0.888$), and Interquartile Age Range ($B = 0.00098$, $p = 0.842$), and Odour Subject Phrase Length ($B = 0.0033$, $p = 0.104$).

Model fit was reasonable (REML criterion = 376.6), and residual diagnostics revealed slight but significant deviation from normality (Kolmogorov–Smirnov test: $p = 0.00118$; outlier test: $p = 0.00419$), though the dispersion test ($p = 0.848$) was non-significant. The random intercept variance for *Book ID* was 0.0097 (SD = 0.0985), indicating relatively low between-book variability in average description length.

4.3.4. Presence of Textual Cues (Binomial GLMM)

To assess which factors predict whether books include textual cues related to odours (e.g., "Scratch and sniff here!"), we fit a binomial generalized linear mixed model (GLMM) with a complementary log-log link. This link function was chosen to model asymmetrical binary outcomes and accommodate low-probability events. A random intercept for *Book ID* accounted for repeated measures within books ($N = 2118$ observations, $n = 333$ books). The model is specified as:

$$\begin{aligned}\operatorname{cloglog}(\Pr(Y_i = 1)) = {} & \beta_0 + \beta_1 \cdot \text{Mean Target Age}_i + \beta_2 \cdot \text{Book Age}_i \\ & + \beta_3 \cdot \text{Interquartile Age Range}_i \\ & + \beta_4 \cdot \text{Odour Subject Length}_i + u_{\text{BookID}[i]}\end{aligned}$$

Where: β_0 is the intercept; $\beta_1, \beta_2, \beta_3$ are fixed-effect coefficients; $u_{\text{BookID[i]}}$ is the random intercept for each book; and a zero-inflation component π was modelled as constant.

Unlike for descriptions, none of the predictors were significant: Mean Target Age ($B = 0.0026$, SE = 0.0121, $p = 0.828$), Book Age ($B = 0.0024$, SE = 0.0052, $p = 0.632$), Interquartile Age Range ($B = -0.0018$, SE = 0.0265, $p = 0.946$), and Odour Subject Phrase Length ($B = 0.0017$, SE = 0.0122, $p = 0.890$).

Model fit statistics were reasonable (AIC = 918.7; BIC = 952.7; log $L = -453.4$). The random intercept variance for Book ID was large (22.99; SD = 4.79), indicating substantial between-book variability in whether textual cues appeared. Residual diagnostics revealed significant deviation from uniformity (Kolmogorov–Smirnov test: $p = 0.01316$), suggesting mild heteroscedasticity, though dispersion ($p = 0.52$) and outlier ($p = 0.3933$) tests were non-significant. This points to some heteroscedasticity, but overall, the model provides a reasonable fit to the data.

4.3.5. Variation in Textual Cue Word Length (Gamma GLMM)

To investigate what predicts variation in average word length within textual cues, we fit a gamma generalized linear mixed model (GLMM) with a log link, appropriate for positively skewed continuous data bounded below by zero. The dependent variable was the log-transformed average word length within quoted textual cues. Only entries with non-zero textual cue word lengths were

included ($N = 1620$ observations, $n = 311$ books), and a random intercept for *Book ID* was used to account for repeated observations.

The model revealed a significant negative effect of Mean Target Age ($B = 0.0023$, SE $=0.0009$, $z = 2.45$, $p = 0.0141$) and Book Age ($B = -0.0007$, SE $=0.0003$, $z = -2.30$, $p = 0.0215$), suggesting that older books as well as books targeting younger readers use shorter words in textual cues (and thus potentially less complex concepts). Conversely, Odour Subject Phrase Length was positively associated with word length ($B = 0.0023$, SE $=0.0004$, $z = 5.22$, $p < 0.001$), indicating that books with longer (more complex) odour subject phrases also use more complex textual cues. Interquartile Age Range was not a significant predictor ($p = 0.7026$).

Model fit was strong (AIC $= -1570.1$; BIC $= -1532.4$; $\log L = 792.0$). The random intercept variance for Book ID was 0.0054 (SD $= 0.0734$). Residual diagnostics revealed significant deviation from expected distribution (Kolmogorov–Smirnov test: $p = 0.00002$), including significant outliers ($p = 0.00003$), though the dispersion test was not significant ($p = 0.16$), suggesting mild heteroscedasticity.

5. Discussion

The aim of this study was to systematically identify the key characteristics of scratch-and-sniff books, based on a comprehensive database. The description is enhanced with an interpretation of the books' role in literature, with the objective to outline the principles that can be applied in future design and analysis studies of this unique, interactive reading genre.

The database comprises 407 titles of smell-enhanced books, which is a relatively low number compared to the average annual publication of 500 000 to 1 000 000 books. When examining the number of titles per age group within this niche area, the publication figures suggest a higher consumer preference for smells intended for children rather than adults. This implies that parents recognize the value of exposing children to odours in books, but this perceived benefit diminishes with age. The limited number of titles may be attributed to practical constraints, particularly the challenge of retaining odours within the book. Additionally, some titles exhibit low concentrations of odours, possibly due to the rapid disappearance of smells on stickers, which may be influenced by storage and usage conditions as well as the quality of microencapsulation (e.g., certain books from the 2010s have lost smell but are often from the same publisher).

When examining the number of titles per age group within this niche area, the publication figures suggest a higher consumer preference for fragrances intended for children rather than adults. This indicates that parents recognize

the value of exposing children to odours in books, but this perceived benefit diminishes with age.

5.1. The relationship between Odours and Cognitive Stages

5.1.1. Olfactory Exposure Hypothesis (H1)

Our findings provided strong support for the Olfactory exposure hypothesis (H1), illustrating clear developmental trajectories in the selection and thematic use of smells across age groups. Books targeted at infants and preschoolers predominantly featured familiar, comforting, and food-based smells such as chocolate, apple, and strawberry. These findings align with developmental literature indicating that early childhood sensory experiences prioritize familiarity and comfort, potentially facilitating initial categorization and sensorymotor exploration (Majid, 2021; Poncelet *et al*., 2010). In early childhood (5–8 years), the olfactory repertoire notably expands to incorporate more varied odours, such as spices and scents associated with natural stimuli (e.g., cinnamon and pine). This shift may reflect an increasing sensory curiosity and readiness for broader environmental exploration.

The transition becomes particularly pronounced in middle childhood (8–12 years), where books prominently feature socially transgressive and bodily smells (e.g., fart, smelly feet, armpit). This aligns closely with known developmental trends emphasizing humour, peer interaction, and social boundary-testing in middle childhood (McGhee, 1979; Rozin and Fallon, 1987). Such olfactory choices not only entertain but may also support important social developmental tasks, such as understanding social norms, disgust, and humour. Notably, our exploratory categorization using Banes' taxonomy revealed that a small subset of smells (Category C, approx. 1.8%) served to complement or contrast audiovisual signs, functioning in ways that are potentially playful or subversive. However, these rarely operated as standalone olfactory jokes (when humour-related); instead, they typically reinforced or reframed a character's traits or actions (e.g., matching a fart to a specific character's identity), suggesting that humour-related smells are still predominantly used referentially (or viscerally) rather than narratively.

By adolescence (12–18 years), the smells used shift again, this time towards abstract, symbolic, or identity-linked odours such as coffee, perfume, and incense, mirroring developmental tasks related to identity exploration and aesthetic self-expression (Doty *et al*., 1984).

Overall, the observed alignment of smell types with developmental stages suggests that smell-enhanced books could help to scaffold children's sensory and cognitive growth. This deliberate structuring of olfactory stimuli potentially supports early developmental processes of sensory categorization, social boundary recognition, and, later, identity formation and symbolic interpretation.

5.1.2. Cognitive Association Hypothesis (H2)

Our results provided compelling support for the Cognitive association hypothesis (H2), revealing clear age-related shifts from direct, concrete smell-object associations to more abstract, evaluative, and inferential cognitive engagements. Books for younger children (0–5 years) used explicit, direct labelling, reflecting developmental preferences for concrete, sensory-grounded cognition (Valentin and Chanquoy, 2012). Such direct labelling likely reinforces object permanence and basic associative learning, consistent with cognitive capacities in the preoperational stage described by Piaget (1952).

Conversely, books aimed at older children and adolescents increasingly leveraged implicit descriptions and evaluative framing (e.g., "this smells gross" or humorous character reactions without explicit smell labels). This shift aligns with the onset of more abstract, inferential cognitive abilities characteristic of Piaget's concrete operational stage. Statistical analyses supported this developmental trajectory by demonstrating fewer explicit odour descriptions with increased target age, potentially reinforcing readers' inferential skills rather than simple linguistic complexity. Notably, older-targeted books also featured longer odour subject phrases (more conceptually complex), which may enhance cognitive engagement through conceptual richness rather than explicit textual detail alone.

This nuanced linguistic strategy could facilitate more sophisticated cognitive and inferential demands, potentially challenging readers to interpret smells through contextual cues rather than explicit instructions. Thus, smell-enhanced books appear to reflect developmental progressions in linguistic complexity and may support critical thinking, perspective-taking, and the flexible interpretation of sensory experiences. Our findings highlight subtle yet potentially meaningful ways these books could contribute to children's evolving cognitive competencies.

5.1.3. Emerging Themes in Middle Childhood and Adolescence

While our primary focus was on early developmental stages, we observed consistent thematic shifts in books aimed at older age groups. In middle childhood (8–12 years), olfactory content increasingly featured socially transgressive smells, reflecting humour and boundary-testing behaviours. By adolescence (12–18 years), books introduced more symbolic and identity-linked smells, such as perfume or coffee, pointing toward evolving aesthetic and affective engagements. Although these patterns are touched on in earlier sections, we highlight them here to suggest how smell-enhanced books may increasingly scaffold socio-emotional development and identity exploration in later childhood.

5.2. Books' Characteristics and Target Age Groups

The analyses reported here would appear to support the suggestion that there are age-related differences in how scratch-and-sniff books present olfactory content. That is, books targeting older readers tend to include longer odour-related phrases but fewer explicit descriptions. This suggests that older readers may be expected to infer sensory details from other contexts (e.g., narrative or visual), or that more descriptive odour subject words reduce the need for further elaboration.

The findings reported here demonstrate that the predominant function of categorized olfactory descriptions within the dataset was illustrative (Category A), comprising 83.3% of all instances. These scents were closely associated with specific objects or characters referenced in the text, thereby reinforcing referential comprehension and underscoring the dominance of illustrative olfactory usage. By contrast, memory-summoning (Category D) and contrast-based (Category C) were rare. One potential reason may stem from structure: scented books are typically short (often under 12 pages), giving authors little opportunity to introduce a smell or concept early and later recall it in a way that meaningfully leverages olfactory memory. We suspect that, in theatrical works (the context in which Banes' taxonomy was developed), longer time spans allow scents to accumulate narrative weight and evoke earlier moments. Although such callbacks are possible even in short-form literature, the temporal constraints and pacing of children's books may discourage such narrative use. This underutilization nevertheless represents an avenue for enhancing reader engagement and emotional resonance in children's literature and should be considered by children's publishers and e-book designers as an avenue for future innovation. Authors and designers might draw more intentionally on smell's mnemonic and affective dimensions to support narrative immersion and learning outcomes.

Interestingly, older books were more likely overall to include odour descriptions, yet their textual cues often used shorter words. While the length of odour subject phrases did not predict whether a description would be included, it did correlate with increased average word length in the accompanying textual cues, suggesting that longer subject phrases may invite more nuanced or sophisticated framing, even if descriptive complexity does not consistently increase.

In reflecting on these findings, we recognize the importance of age-appropriate olfactory depictions in children's literature and the potential for more metaphorical and inferential uses of smell as readers mature. While younger audiences may benefit from direct and illustrative olfactory cues that support comprehension and sensory grounding, literature for older children could more effectively harness smell as a symbolic or emotional device,

enriching narrative subtlety and interpretive depth. Other sensory storytelling media, such as theatre and digital games, have been integrating smell in more immersive and expressive ways than books and as such, offer valuable inspiration for future literary and educational applications, and underscore the need for continued interdisciplinary inquiry into how smell can foster story engagement across media. Harnessing a broader range of olfactory functions (especially contrast and memory) may represent untapped opportunities for enriching reader engagement and emotional depth in children's books and could be leveraged by future authors.

5.2.1. Linguistic Complexity Hypothesis (H3)

We hypothesized that those books targeting older children and adults would feature longer (and thus more complex) olfactory descriptions than those aimed at younger readers. Our findings provide partial support but highlight the complexity of interpreting linguistic complexity from observational data. Older-targeted books did contain longer descriptive words, but explicit descriptions were less frequent, potentially indicating a shift from direct sensory labelling to more inferential or contextually embedded representation.

Moreover, the shorter average word length in textual cues for older books complicates the assumption that linguistic complexity uniformly increases with age. Instead, the trend may reflect a stylistic shift toward concise or context-driven expression, rather than syntactic elaboration. Overall, while descriptive length increases with target age, complexity remains ambiguous, warranting further investigation into syntactic and narrative strategies.

Additionally, while older books were more likely to contain odour descriptions, their textual cues used shorter words (less conceptual complexity). Importantly, odour subject phrase length (conceptual complexity) did not predict whether a book contained descriptions but was positively associated with textual cue complexity.

These results indicate that while older-targeted books may feature longer olfactory descriptions, they do not necessarily adopt greater syntactic complexity. Instead, the decrease in explicit descriptions suggests a transition toward more inferential or concise representations of smell, potentially aligning with readers' increasing ability to derive sensory meaning from context. However, the unexpected trend of shorter words in textual cues for older books suggests that linguistic complexity may not uniformly increase across all descriptive elements. Consequently, while the length of olfactory descriptions increases with target readership age, their complexity remains ambiguous, warranting further investigation into structural and syntactic patterns. The age-related and chronological differences in odour description are likely to have been contributed by publishing trends and pedagogical goals.

5.2.2. *Implicit* vs. *Explicit Smell Description Hypothesis (H4)*

This hypothesis suggested that books targeted at older readers would rely more heavily on implicit textual cues or descriptions, whereas books for younger readers would feature explicit smell instructions (e.g., "Scratch here to smell the apple") or descriptive elaborations (e.g., "The cake smelled sweet and warm"). The findings generally *support* this hypothesis.

The results indicate that books for older audiences contain fewer explicit odour descriptions, aligning with the expectation that older readers are required to infer sensory details from context rather than rely on direct prompts. While textual cues in older books were found to use shorter words, this does not necessarily contradict the hypothesis. Implicit descriptions may be achieved through broader narrative context. Thus, the observed reduction in explicit descriptions in older-targeted books aligns with the developmental transition from direct sensory labelling in early childhood to more implicit linguistic representations of smell in later years.

5.3. *Fragrance and Form: Literary Constraints and Critical Debates*

The use of smells in scratch-and-sniff books has long been debated, with early critics questioning whether smell-driven storytelling enhances or diminishes literary quality. For instance, Maynard (1973) sharply critiqued these books as "nonbooks" or mere "paper toys", arguing that their plots often serve merely as scaffolds for introducing smells. She also criticized the textual cues meant to guide sniffing (such as "Here, take a sniff at this fruity spiced cake") for being shallow invitations to engage with smell rather than meaningful literary prompts. Similarly, Oliver (1977) noted that smells were often inserted with minimal narrative justification, resulting in disjointed transitions and text that served more to cue the next smell than to advance the story. Amoss and Suben (1999) added a cautionary note about commercial design decisions that prioritize novelty over narrative coherence, warning against the use of generic or leftover fragrances to represent undefined concepts such as dinosaur smells.

These critiques reflect broader concerns about authorial intent and design constraints, and they are not without basis. Interviews with designers using scratch-and-sniff technologies (Brooks and Lopes, 2023) revealed that projects often begin with available fragrance catalogues, not conceptual needs. A similar pattern emerges in Jan Berenstain's reflections on the development of *Papa's pizza: A Berenstain bear sniff book* (1978), where the narrative was in-part guided by a microencapsulation company's smell catalogue, prompting them to build a pizza-making story around the pre-existing smells of tomato, cheese, and dough (Weiss, 2001). As she noted, "As if having to incorporate a limited vocabulary into a book isn't challenging enough, Random House also gave us fragrance labels to use in special books." Her comment highlights an

important parallel; children's books already operate within tight constraints: linguistically and, in the case of smell-enhanced ones, olfactorily.

However, the presence of these constraints does not necessarily diminish the cognitive or literary value of the final product. If smell-enhanced storytelling appears limited by what smells are available in a smell catalogue, so too is children's literature limited by early reading levels, vocabulary lists, and publishing norms. Yet these constraints do not necessarily render the resulting works meaningless. On the contrary, constraint-based design can be valuable for educational media (Mitrovic, 2012), and scratch-and-sniff books exemplify how multimodal constraints could still support narrative engagement, language development, and sensory learning.

While some critics argue that scratch-and-sniff books sacrifice literary depth in favour of interactive novelty, such critiques often overlook the cognitive and experiential value that smell brings to the reading process. As Spence (2020) reflects, olfactory elements can make stories incredibly memorable: *The enchanted island* (1972), for instance, remains the only children's book he vividly recalls from his youth, precisely because of its smells. This potential becomes especially apparent when we examine how olfactory elements may function cognitively: not just as gimmicks, but as meaningful scaffolds for learning and perception.

5.4. Smell as Scaffold: Crossmodal Learning and Interpretive Gaps

Our analysis suggests that, rather than detracting from the reading experience, smells may function as cognitive scaffolds and socialization tools, shaping how young readers engage with both language and sensory input. By strategically incorporating textual cues, labelling, and olfactory contrasts, these books help children build crossmodal associations, enabling them to map verbal descriptions onto sensory experiences: a foundational process in symbol grounding and early concept formation (Glenberg and Robertson, 2000; Yu and Smith, 2012). This design supports both language development and the construction of sensory categories.

This scaffolding of crossmodal association does more than merely facilitate basic vocabulary acquisition: it supports the emergence of social cognition. By linking sensory input with affective response and narrative structure, these books lay the groundwork for how children begin to interpret smells not just as sensory stimuli, but as emotionally and socially meaningful cues. Scratch-and-sniff books guide readers' interpretation of odours through social referencing, reinforce culturally normative judgments about smells (e.g., what is considered "good" or "bad"), and create space for playful or subversive engagements with olfactory norms. From a cognitive perspective, this blend of labelling,

affect, and interactive narrative structure encourages perspective-taking, inferential reasoning, and emotionally grounded learning, all of which contribute to early narrative competence.

For example, in *Sesame street: A sweet-smelling garden* (2010), the textual representation of fruit odours is often deliberately sparse or non-existent. Instead of detailed descriptions, the book prompts engagement through open-ended questions like, "Do you think this scent is good?", leaving space for joint attention, caregiver scaffolding, and child inference. This approach fosters inferential meaning-making, allowing children to construct associations between language, smell, and emotion through interaction.

This aligns with pedagogical principles in children's literature that value leaving interpretive gaps to foster active meaning-making (Nikolajeva, 2010). Building on Nikolajeva's notion of textual and pictorial gaps (2010), we argue that olfactory cues in scratch-and-sniff books operate as an additional interpretive code. These gaps encourage children to engage with narrative on both a sensory and symbolic level, constructing meaning through inference rather than direct instruction. In doing so, smell-enhanced books potentially support multisensory narrative comprehension and nurture literary competence by extending familiar literary strategies into the sensory domain.

5.5. Smell as Subversion: Reframing Odour Categories Through Play And Perspective-Taking

This process of labelling becomes especially cognitively rich when familiar smells are paired with unexpected or humorous linguistic frames. In so-called "malodorous" books, the actual fragrances are sometimes in reality relatively neutral or pleasant, but their labels radically shift their interpretation. For example, Kavet's *The scratch and sniff fart book* (1997) uses common scratch-and-sniff fragrances (fish, cheese, floral, etc.), but changes their textual label (farts), descriptions, and context drastically. Likewise, *Little Monster's scratch and sniff mystery* (1980) employs labelling as a distancing device, estranging common smells from their everyday meanings to create playful dissonance.

Such re-labelling invites children to engage in semantic recontextualization: the flexible interpretation of identical sensory inputs within different conceptual frames, which can significantly impact olfactory perception (Herz, 2003; Herz and Von Clef, 2001). This kind of interpretive flexibility supports symbolic play, metalinguistic awareness, and the development of context-sensitive meaning-making, all key facets of early cognitive and language development (Nicolopoulou, 1997). Importantly, these examples also underscore the socially constructed nature of odour categories and highlight how scratch-and-sniff books allow children to experiment with, question, and even parody shared olfactory norms.

As Nikolajeva (2009, p. 21) writes of pony stories, such narratives allow girls to be "everything that normally contradicts female stereotypes: strong, enterprising, independent, competitive, while at the same time retaining their traditionally feminine traits." Scratch-and-sniff books, we suggest, may serve a similar function for olfactory behaviour: they give young readers, who are frequently reminded not to engage with or express delight in bad smells, the opportunity to transgress those norms (through smell and often humour) within the protective structure of a smell-enhanced book.

This subversive potential appears to be developmentally targeted. Our analysis of top smells revealed that so-called "bad" smells (especially bodily ones such as foot, fart, armpit, poop, and sweat that are taboo and transgressive) cluster around target readership ages of 8–12 years. This period, often associated with heightened awareness of social norms, embarrassment, and bodily boundaries, such as increased sensitivity to what is considered private or appropriate regarding the body (Corsaro, 2003; Pellegrini and Smith, 1998), may be a particularly potent moment for readers to engage in norm negotiation through sensory play. These books do not simply entertain; they may provide children tools to explore and reframe culturally fraught aspects of embodied experience.

In addition to fostering inference, smell-enhanced books also create opportunities for reader-character alignment through shared olfactory experience. Some titles use bad smells not just for humour or subversion, but to empower readers to participate in the narrative; responding "yuck!" in unison with a character, for instance, may foster a sense of identification and agency (Nikolajeva, 2014). Kucirkova and Littleton (2020) suggested that allowing children to manipulate story elements (such as digital characters) may foster identification and empathy. Likewise, Brooks (2023) observed that in scratch-and-sniff films, audience reactions to smell alongside characters could be impactful: when viewers' sensory responses align with a character's, viewers anecdotally wrote about a heightened sense of connection. For instance, nearly twenty years after the experience, one viewer recalled feeling pride in reacting with disgust to a fishy smell in unison with the characters Phil and Lil in *Rugrats go wild* (2003).

Extrapolating from these insights, the way characters interact with and respond to smells could influence the reader's perception. A character expressing delight at the smell of freshly baked cookies, for example, not only reinforces the pleasantness of the odour but also integrates it into the character's experience and the story's emotional fabric. Through these mechanisms, smell-enhanced books may foster empathic perspective-taking *via* multisensory cues.

Yet not all smell-enhanced books encourage this kind of imaginative alignment. Just as some invite readers to playfully transgress olfactory norms or

connect with characters, others perform a quieter kind of olfactory discipline: guiding children toward culturally sanctioned interpretations of certain smell.

5.6. From Scented Play to Scented Power: Socialization and Ideology

While certain smell-enhanced books encourage subversion or sensory experimentation, others work in the opposite direction: they socialize children into culturally accepted interpretations of smell (Herz, 2008). This is particularly evident in books aimed at younger readers, where labelling is used not to provoke, but to gently introduce, normalize, and reinforce desirable olfactory associations. In these cases, smells serve less as a vehicle for norm negotiation and more as a scaffold for sensory acculturation. This aligns with aspects of Montessori education, which emphasizes structured exploration of sensory stimuli (including smell) as a foundation for cognitive and social development (Lillard and Else-Quest, 2006). In both Montessori settings and smell-enhanced books, sensory experiences are carefully curated to guide children toward culturally valued distinctions and preferences.

This acculturative role is especially clear in *Sesame street: A sweet-smelling garden* (2010), where fruit odours are framed not simply as pleasant, but as socially and morally valuable. The story centres around encouraging Oscar the Grouch to appreciate fruits: not just for how they smell, but because they are "yummy" and, implicitly, good for you. Readers are invited to scratch and sniff sweet, fruity odours while the characters model enthusiastic reactions and reinforce the message through language. For example, after initially resisting, Oscar eats a strawberry and concedes that it is "pretty delicious." This moment aligns olfactory cues, character behaviour, and evaluative language to form an early association between sensory pleasure and virtuous consumption.

Rather than relying on detailed descriptions, the book coordinates smell, simple text, and character response to construct a value-laden message: fruit smell good, taste good, and are good for you. This layering of modalities (olfactory, textual, and social) illustrates how smell-enhanced books may function as tools of early cultural socialization. Notably, the book occasionally uses open-ended questions (e.g., "Do you think this scent is good?"), which invite child readers to participate in the interpretive process—yet the surrounding narrative structure and character reactions often nudge them toward a culturally normative answer. These prompts create the impression of autonomy while quietly reinforcing shared values. In this way, smell-enhanced books do not just teach children what smells good; they guide them toward what *ought* to be liked, using smell as an affective and moral scaffold for broader normative frameworks around health, behaviour, and desire. This alignment of narrative elements is what elevates smell-enhanced books into a unique literary genre.

As Kucirkova and Jensen (2023) argue, olfaction carries a unique communicative affordance, comparable to colour in its ability to direct a reader's attention and encode meaning. However, as we move towards literature aimed at teenagers and adults, the ideological work of smell often becomes more overt—and more troubling. For instance, in Kavet's book, smells are employed to reinforce gendered and racialized stereotypes (Kavet, 1997). The "Lover's fart", rendered as a fishy smell, alludes to female genitalia, while farts labelled as "Foreigner's" or "Exotic Spice" trade on long-standing orientalist and xenophobic tropes. While the book is marketed as humour, these smell associations are not left open to interpretation: characters often react with disgust or ridicule, thereby modelling specific affective responses for the reader. The olfactory cues are not just jokes: they are embedded judgments, inviting laughter at and revulsion toward particular bodies and identities. Such representations do not simply reflect cultural bias; they perpetuate it, assuming and reinforcing a Western male perspective under the guise of comedy.

Taken together, these examples underscore the multifaceted role of olfaction may have in smell-enhanced literature. In books for younger readers, olfactory cues may serve to build consensus around what is "pleasant" or "good." In older-targeted texts, those same cues may become tools for encoding and reproducing social hierarchies, cultural stereotypes, and ideological norms. This dual role (comforting and guiding the young reader, while reinforcing or challenging norms for older audiences) highlights the significance of smell beyond the sensory level.

Even when seemingly redundant or pleonastic, olfactory elements in smell-enhanced books may operate as potent tools for socialization and acculturation. They impart societal norms and expectations to young readers and may reflect or reinforce more problematic ideologies for adult audiences. This duality presents both an opportunity and a responsibility for authors, designers, and publishers to consider the implicit messages conveyed through smell.

5.7. Smell as Scaffold: Crossmodal Learning and Interpretive Gaps

Our findings suggest age-progressive strategies for integrating olfaction into children's media:

Grounding (approx. 2–7 years): concrete, familiar, and supportive. Because early comprehension relies on redundant multisensory cues and familiar categories (Shams and Seitz, 2008; Talsma *et al.*, 2010), pair illustrative scents (Category A), especially familiar food and nature odours, with clear visual labels and simple prompts to strengthen word-referent mapping, early category learning, and emotional safety. Keep cues redundant (text, image, and scent) and avoid ambiguous or mixed signals. Use gentle contrasts (clean *vs.* dirty, sweet *vs.* sour) sparingly to introduce evaluative language without confusion.

Elaborating (approx. 7–12 years): comparison, inference, and play. As children begin to form semantic categories for odours and use labels to support reasoning (Poncelet *et al*., 2010; Valentin and Chanquoy, 2012), designers can use smells to scaffold comparison (sweet *vs.* pungent; fresh *vs.* stale), bolster inference (fewer explicit descriptors and more context), and invite humour and subversion (benign "gross" cues) to practice social-norm negotiation. Consider small callbacks within the book (same scent referenced across two scenes) to begin cultivating scent-based narrative memory.

Symbolizing (12+ years): mood, identity, and narrative callbacks. By adolescence, smells can cue emotional states, symbolic associations, and identity-linked meaning (Herz, 2003; Majid, 2021). Designers may want to experiment with mood and ambience (Category B), ritual (Category E), and symbolic scents (e.g., coffee, incense, perfume) to support theme, setting, and identity exploration. Where length permits, use scent callbacks and cross-scene references to leverage olfactory memory: an underused but potent device. Be mindful of stereotype propagation in humour or identity-coded scents; author notes, textual cues, or end-matter can contextualize choices and promote critical literacy.

Negotiating meaning (all ages): socialization and perspective-taking. Our corpus shows that titles sometimes include guiding readers toward culturally sanctioned evaluations, which can be pedagogically useful but risks narrowing interpretive space. To balance guidance with agency, smell cues can be designed to surface divergent viewpoints (e.g., two characters reacting differently to the same odour; a character changing their mind across scenes) and to invite reflection ("What do *you* think this smells like? Why might X like it and Y not?"). Such designs align with socio-cognitive development by encouraging children to infer others' mental states from multisensory context, practice norm negotiation safely, and recognize olfactory judgements are contextual, cultural, and perspectival rather than fixed.

Together, these principles highlight how olfaction can evolve from scaffolding concrete comprehension to supporting socio-emotional growth and symbolic interpretation, underscoring its potential as a developmental design material.

6. Study Limitations and Future Directions

While this study provides a comprehensive analysis of smell-enhanced books, several methodological limitations must be acknowledged. First, the use of lemmatized words in the analysis might not fully capture the nuances in fragrance descriptions. Terms like "chocolate cake" could ambiguously fall under categories like "chocolate" and "baked goods", potentially limiting the accuracy of odour categorization. Future studies could employ more advanced

natural language processing methods, such as semantic embedding techniques or supervised classification, to delineate olfactory categories from textual representations.

Second, although extensive, our corpus might not encompass all published smell-enhanced titles. Our reliance on systematic literature searches, notably supplemented by additional resources like WorldCat.org, offers significant coverage due to its aggregation of multiple library catalogues (universities, high schools, public libraries, and elementary schools), where such books are likely more prevalent. Nonetheless, rare or foreign titles could remain underrepresented. Future research should continue to expand corpus databases by integrating additional resources, including direct publisher records and international databases.

Third, single-annotator coding is a limitation of the current study. Because many titles were not digitized and required in-person access to physical copies, all coding was performed by the first author, a domain expert in olfactory media. This ensured consistency and domain-informed judgements, but it also precluded the calculation of inter-rater reliability metrics. Future work may aim to incorporate multiple annotators and independent coding to enable inter-annotator agreement measures and quantitatively refine the coding scheme.

Additionally, several statistical and analytical limitation were identified. The significant residual deviations and heteroscedasticity detected in some statistical models suggest that predictors may not fully capture all underlying variance. These deviations imply complexities in factors influencing descriptor and textual length that were not entirely accounted for. Consequently, future analysis might benefit from including additional predictors such as narrative style, intended emotional response, or multimodal elements like visual cues.

The identification of outliers in textual cue models suggests substantial variability in writing styles. This variability may reflect genre differences, editorial standards, or specific audience expectations. Further research could examine genre-specific trends more explicitly, incorporating qualitative or computational analyses, such as thematic or genre-specific topic modelling, to elucidate these differences in writing style and olfactory description patterns.

Another limitation is the lack of granular categorization for books targeting adult readers. Unlike children's literature, adult-targeted books are often broadly categorized as "18+", which constrains detailed analysis of specific age-related preferences or trends. Future research could incorporate refined age classifications or use methods like author attributions or crowd-sourced assessments to enhance categorization accuracy and gain precise insights into age-specific odour changes within adult-targeted books.

A final limitation is that the dataset analysed here is limited both culturally and linguistically as it is predominantly composed of Anglophone texts. This concentration may have influenced both the frequency and nature of olfac-

tory references, and our findings may merely reflect cultural particularities. To address this limitation, future research should seek to expand the corpus to encompass a broader range of titles, thereby enabling more comprehensive and generalizable conclusions about how smell is depicted and functions narratively within children's literature across diverse cultural contexts.

While our study is grounded in theory-driven hypotheses, some interpretations remain observational and speculative. Future work could use experimental designs to empirically test the causal effects of odour types, olfactory descriptions, and textual cues on cognitive and developmental outcomes. In summary, our analytical framework and findings lay a foundational basis for future studies. Addressing these methodological limitations and expanding research approaches will enable deeper insights into the cognitive, linguistic, and developmental implications of smell-enhanced books across diverse reader populations.

7. Conclusion

In conclusion, our contributions are threefold: (1) we provide the first large-scale, age-sensitive analysis of smell-enhanced books, identifying potential developmental patterns in smell selection and olfactory representation; (2) we introduce a novel approach to analysing olfactory linguistic complexity, integrating word length as a proxy for conceptual depth; and (3) we advance theoretical models by demonstrating how smell in books may also function not only as sensory enhancement but also as a scaffold for cognitive development, symbolic reasoning, and cultural socialization.

Together, these findings suggest that smell-enhanced books (often dismissed as novelty items) deserve more serious consideration as multimodal learning tools. By tracing how olfactory content and linguistic framing shift across age groups, we show that these books may participate in broader developmental processes, from sensory categorization in early childhood to social norm negotiation and identity formation in later years. While our analysis does not directly assess reader interpretation or learning outcomes, it offers a data-rich foundation for future work on how smell, language, and meaning co-develop in early reading experiences. As interest in multisensory literacy grows, we hope this study encourages further research into how underexplored modalities like olfaction can contribute to children's engagement with books and with the world around them.

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