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Microfibres and health: State of the evidence and research gaps

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ABSTRACT

Microfibres are ubiquitous in the environment and there has been an increasing focus on health harms from them in recent decades. The current WHO guidelines defining health risks from microfibres focus on just the subset of microfibres that are inorganic and respirable. Recent studies have revealed large volumes of textile microfibres are present throughout the environment and that non-plastic microfibres are as common or more common than plastic microfibres. However, these are rarely included in the analysis of harms. This narrative review of textile microfibres sets out the state of our understanding of exposure to and harms from textile microfibres. We found that the epidemiological research reviewed here does not support the continued focus solely on the respiratory route of exposure nor only on plastic microfibres as hazardous to health. In fact, gastrointestinal as well as upper airway effects may also be increased by exposure to textile microfibres. Importantly, microfibres behave differently in the environment, and within the body in comparison to non-fibre particles, and therefore warrant separate investigation from particles and microplastics. The conclusion of this cross-disciplinary review is an urgent call for greater investigation of textile microfibres, separately from the also important issue of microplastics, and therefore, the inclusion of non-plastic fibre types in research going forward.

1. Introduction

The potential for hazardous exposure to microfibres from textiles is coming to our attention via a circuitous route. What has been discovered in starting to measure and count plastic pollution particles in the environment has been staggering. For instance, significant numbers of plastic fibres were found at the top of mountains (Brahney et al., 2020), in Arctic ice floes (Bergmann et al., 2019), and in the depths of the ocean (Kane et al., 2020). Plastic fibres have been found to be consumed by organisms throughout the food chain, from the tiniest zooplankton (Cole et al., 2013) to farmed fish (Walkinshaw et al., 2022) [5] and even terrestrial predators (Nessi et al., 2022). Despite this alarming proliferation of outdoor exposure data, pointing towards the ubiquity of microfibres throughout the environment, the sources of the pollution have remained, in large part, unclear (Brahney et al., 2020).

Plastic pollution has received global attention in recent years, leading to the current development of international agreements to reduce plastic waste (United Nations, 2022), meaning that once these agreements are signed and ratified by signatory governments, we can expect plastic pollution to be reduced over the next several decades. Among the various forms of plastic, microplastics—defined as any plastic particle with a diameter smaller than 5 millimetres—pose the most significant environmental threat. This is primarily due to their ability to travel long distances and be consumed by a wide variety of organisms. Larger pieces are classified as meso-plastics. Microfibres fall into the category of microplastics, which also includes fragments, films and spheres. Notably, fibres represent the largest fraction of microplastics, accounting for 70–100 % of microplastics found; in surface water (91 %) (Barrows et al., 2018), deep sea (70–100 %) (Kane et al., 2020), and plastic pollution “rain”, deposited from the atmosphere (100 %, 70 %, 92 %) (Brahney et al., 2020; Gasperi et al., 2018; Wright et al., 2020). From this evidence, it appears that the environment is saturated with microfibres.

However, not all, or even most, of the fibres collected are “plastic”, derived from petrochemical sources. Research indicates that a significant proportion of these fibres, often overlooked in analyses, are actually non-plastic. For instance, one study found that while 95 % of meso- and micro-sized litter particles collected in ocean surface waters near Africa were microfibres, plastic microfibres only accounted for 6 % (Weideman et al., 2023). The other microfibres found included 59 % natural fibres,

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Table 1
Schema describing the state of evidence in each topic area.

Absent	Emerging	Active	Mature
Denotes a lack of papers specifically on this topic. Evidence may be available, as incidental reporting in studies of another topic area (often microplastics).	Studies focused on this specific research area are available. Some studies are starting to build on earlier research from others.	Studies are common in this specific research topic, building on earlier findings from previous research.	This area of research is generally considered to be established, with important conclusions generally agreed upon.

including cotton and wool, and the largest proportion was cellulosic (e.g. rayon, a manufactured cellulose polymer fibre) (Weideman et al., 2023). Similar findings were reported in the UK, where the highest proportion of fibres identified from urban air atmospheric fallout were also cellulosic (Napper et al., 2023). In Paris atmospheric fallout, half of the fibres were non-plastic, primarily cotton and wool (Dris et al., 2016). Across these three studies, fully plastic (petrochemical) microfibres represented only between 6 % and 30 % of the samples.

These data suggest that microfibre pollution likely originates from different sources, than other plastic pollution. Furthermore, the fibres found in environmental pollution must have substantial and unexplained differences to other micro-particle pollution. We review here the current state of research in the various subtopics which relate to microfibres research to highlight the fact that while some areas have a strong record of excellent research, other topics are reported only incidentally in research conducted on a different topic (most frequently microplastics). Importantly, recent occupational studies and emerging research in animal studies point towards the need to review the 2000 World Health Organisation (WHO) Workshop on which fibre types and sizes pose harm to human health (Greim et al., 2001), and for consideration of human health harm from the same fibres being currently found in such large numbers throughout the globe.

While there has been significant attention on plastic fibres, other types of fibres, such as non-plastic fibres, have not received the same level of investigation. This difference in treatment between plastic and non-plastic fibres is not due to their health relevance or a difference in exposure levels, but simply to the availability of funding for pollution studies, which has encouraged research on “plastics”. In fact, research points to much of the biological harm from minute particles as being related to their physical properties, i.e. size and shape (Greim et al., 2001; Wright and Kelly, 2017) so ignoring non-plastic fibres on this basis is unjustified. Studies which have compared the health impacts of plastic and non-plastic fibres have not, to date, identified plastic fibre pollution as more harmful (Bucci et al., 2020; Pittura et al., 2022).

This paper discusses the current state of research on the exposure to and health impact of microfibres, both plastic and non-plastic. The question this paper poses, is “What evidence exists, or is still needed, in order to understand the human health impacts of microfibres?” This review cannot answer this question, but what we can offer, is to define what research is needed to answer it, and to review the literature in each relevant subtopic, asking; “What is known and what is still needed to decide on the human health risk?”. From this perspective, there is currently no reason to differentiate between plastic and non-plastic fibres. Our exploratory method relied less on database searches, since searches of “(micro)fib*” or “(micro)fib* AND health” return hundreds of thousands of papers on the use and efficacy of microfibre products in medical, scientific and industrial equipment, meaning a systematic approach was inappropriate. Instead, we used a snowballing/citation chaining technique, following the references in papers which were initially identified from such searches which reported on the environmental levels or health impacts of microfibres. Our narrative review also includes research on the physical properties of fibres, the vast bulk of which comes from industry. To classify the level of understanding, we used a four-level rating tool, which is defined in Table 1.

Table 2
Comparison of currently used definitions of the term “microfibres”.

Field	Diameter
Marine science/pollution research	≤5.000 mm [8]
Textile industry (grading)	≤0.010 mm [15]
Human health	≤0.003 mm [31]

2. What is a microfibre?

In this section, we describe the various ways microfibres are defined in different fields. We highlight the urgent need to resolve conflicting terminological use.

2.1. *What is “micro”?*

There are significant differences in how various groups use the prefix “micro”. In the introduction, we described microplastics, which environmental scientists define as particles of less than five millimetres in diameter. Consequently, pollution studies typically classify any fibre five millimetres or smaller as a microfibre. Conversely, the WHO defines microfibres as less than three microns in diameter. This WHO definition is based on the potential risk to human health (currently recognised as only the respirable fraction) (Greim et al., 2001).

The discrepancy between the two definitions means that very few fibres defined in pollution studies as microfibres (or microplastic fibres) would meet the WHO definition for microfibres, as the WHO’s standard is several orders of magnitude smaller (Table 2).

The textile industry has an additional category of “ultrafine” fibres, where many fibres that meet the WHO microfibre definition would be classified as ultrafine fibres by the textile industry (Burdett and Bard, 2006). Table 2 highlights the significant differences across the three considered fields.

The fibre size currently set in WHO guidelines may be too small since they are designed only to identify respirable fibres (Greim et al., 2001). In contrast, the fibre size from pollution research is likely too large.

Another problem with the current pollution studies microfibre definition is that it does not distinguish between diameter and length. It is the diameter of fibres which is likely the defining health-relevant characteristic, and a fibre with a diameter of 5mm is not “micro” but a rather large fibre.

There is an urgent need to reach a consensus on the definition of microfibre since, without such agreement, exposure studies may not be measuring and reporting on the most health-relevant fraction(s) (Dris et al., 2017).

More evidence is needed about fibre characteristics to determine the most appropriate way of defining them. For example, important parameters could be the size (diameter) which a fibre can pass between epithelial cells in the digestive tract to enter the body cavity or bloodstream. Also, the size at which fibres are most likely to remain airborne (for a defined period) may also be important for predicting exposure. For this reason, it may be worth considering a fibre definition based on linear density, as used by the textile industry (Burdett and Bard, 2006).

One recommendation that can be adopted prior to fully understanding these factors would be to rename the respirable fraction, identified by the WHO workshop as harmful to human health, as ultrafine fibres, allowing for fibres above 3 microns, but below 5 mm to keep the definition of microfibre until health-based definitions for larger fractions are defined.

2.2. *Types of microfibre*

On top of issues with the size definition of a microfibre, there is also a lack of consistency in terminology around fibre types. For example,

Table 3
The state evidence and gaps in microfibres research.

Topic	Subtopic	The current state of research	Specific research needs	Important evidence from this topic
What is a microfibre?		Absent	Because organic microfibres are not currently considered a health hazard, microfibres are studied only incidentally in pollution research and industrial research. Therefore, health-based definitions of microfibres, beyond respiratory effects, are urgently needed.	There is an urgent need to separate the study of microfibres from microplastics research, which is a separate topic, albeit with some overlap.
	What is micro?	Absent	Terminology is different across disciplines. Urgent agreement on definitions is needed so that health effects and exposure studies focus on the most important range of sizes.	The definitions currently used in WHO guidelines may be too small, while definitions from pollution research may be too large.
	Types of microfibre	Mature	Degradation characteristics of different microfibres have been researched mainly from an industrial perspective for the purpose of improving fabric quality. A shift in focus towards pollution generation and transport characteristics is needed.	Good information is available on the manufacture, chemical and physical makeup of microfibres.
	Inorganic Fibres	Mature	Sufficient.	Good information is available.
	Organic Fibres	Mature	Research on degradation and transport in the environment is needed.	Industry needs are well understood.

rayon is referred to in various ways, including “artificial” (Dris et al., 2016), “semi-synthetic” (Burdett and Bard, 2006), “synthetic man-made” (Burdett and Bard, 2006) or “cellulosic” (Pauly et al., 2025). Additionally, pollution studies typically categorise fibres from petrochemical-based polymers as “plastic” (Wright and Kelly, 2017). Plant and animal fibres are commonly grouped as “natural fibres” although they have significantly different chemical compositions. All fibres can be categorised as either organic or inorganic, with each category further broken down into naturally occurring or manufactured fibres. All textile fibres are organic, as they consist of carbon-based molecules. While both inorganic and organic fibres may be used in industrial and construction applications, textiles are exclusively made with organic fibres. Organic fibres can either be naturally occurring or manufactured. Naturally occurring organic fibres can include those derived from plants, such as cotton, or from animals, such as wool or silk which grow in fibre form. Organic fibres can also be manufactured from raw materials such as latex or through chemical processes to produce polymers. For example, petroleum is used to create polymers from which we derive nylon, polyester, acrylic, polypropylene and many others. Cellulose polymers are generated from wood pulp from which we get rayon, viscose etc.

The authors recommend avoiding the terms synthetic (typically referring to plastic) and semi-synthetic (denoting manufactured cellulose fibres), as well as natural. This is because, all manufactured fibres originate from a “natural” source (for instance, oil is extracted from the ground). Therefore these terms are misleading. Instead, we recommend all fibres be described, in the first order, as organic or inorganic, and second order definition as naturally forming or manufactured, and in the third order definition, organically manufactured fibres, as plastic (petrochemical-based), cellulosic (manufactured from cellulose polymers) etc. Table 3 provides a summary of evidence (using the four levels rating tool) regarding the microfiber definition.

3. Microfibres and human health

Organic fibres, used in textiles, often have chemicals associated with them. These are either added during the processing or are adsorbed by the fibres from the environment. This section explores these two routes of chemical addition to microfibres and how they could potentially contribute to health risks.

3.1. Chemicals associated with microfibres during processing

Plastic polymers are generally considered chemically inert (Wright and Kelly, 2017). However, numerous additive chemicals may be used for different functions becoming part of the inherent structure of both plastic and cellulosic fibres. Since these chemicals are often not chemically bound into the polymer, there is potential for leaching (Barker, 1975). Such chemicals include metal salts and oxides used as tracers (Barker, 1975). These allow producers to identify batches of their own product by using X-ray diffraction or similar methods. Plastic fibres are also likely to include titanium dioxide as a delustrant, to reduce shine. Additives also include flame retardants and chemicals to reduce static and increase lubricity (smooth feel), which is important for the efficient production of textiles using large-scale industrial plants. Traces of catalysts used in the production of the polymer can also remain in the final product (Barker, 1975). Cellulosic fibres frequently use chemicals that reflect ultraviolet (UV) light as brighteners to make them appear whiter, and chemicals, including formaldehyde, are used to enhance permanent press (Barker, 1975).

Cotton fibres may contain herbicide residues due to the common practice of spraying the plants prior to harvest to promote leaf fall, which aids the harvest process (Barker, 1975). Wool has been shown, at times, to contain toxic metals such as cadmium and arsenic, which are absorbed through the animal’s diet (Wilkinson et al., 2003). Textiles also generally carry dyes, of which there is a huge variety which is constantly increasing (Greenpeace, 2013). The recognition of environmental pollution caused by the textile industry comes largely from the dyeing aspect of textile production and has led to a number of initiatives aimed at reducing toxic chemicals from entering the environment (Changing Markets Foundation, 2017; Greenpeace, 2013).

3.2. Chemicals adsorbed on microfibers

In addition to these inherent chemicals, fibres can also adsorb contaminants from their environment. Indoor air often contains volatile and semi-volatile organic compounds (VOCs and SVOCs) that originate from household products such as air fresheners, cleaning products, and insecticides, as well as leaching from building materials and furnishings such as formaldehyde, phthalates, and flame retardants (Taptiklis et al., 2017). Some of these pollutants may also be carried indoors on clothes or through the air, such as commercial pesticides and polyaromatic hydrocarbons from traffic pollution. Research has shown that cotton fibres can adsorb significantly higher levels of SVOC phthalates than polyester fibres (Morrison et al., 2015). While new, plastic fibres tend to resist the adsorption of such airborne chemicals. Evidence from marine pollution studies suggests that plastics become more prone to adsorb volatile and semi-volatile compounds once they start to degrade (Smith et al., 2018). Plastic degradation occurs primarily due to exposure to heat, UV light, including sunlight, and oxidation reactions (Smith et al., 2018). Cellulosic fibres have not been specifically evaluated for their ability to adsorb airborne contaminants; however, they are likely to

Table 4

The state of the evidence for chemicals in organic microfibres.

Topic	Subtopic	The current state of research	Specific research needs	Important evidence from this topic
Chemicals associated with textile organic microfibres		**Active**	Health risk from ingestion under realistic exposure scenarios needed.	Organic textiles, especially non-plastics, adsorb and release SVOCs and are, therefore, a potentially important vector for exposure to phthalates, fire retardants and pesticides.
	Chemicals added during processing	**Emerging**	How important are textile microfibres as a vector of exposure to inherent chemicals?	Some information is available on dermal exposure. No information is currently available on the likely realistic level of harm from ingestion.
	Adsorbed chemicals	**Emerging**	How important are textile microfibres as a vector of exposure to adsorbed chemicals?	No information is currently available on the likely realistic level of harm from ingestion of adsorbed chemicals.

behave similarly to cotton which is also a cellulose fibre. Research conducted in homes that were commercially cleaned after being used illegally as methamphetamine production laboratories showed ingestion of residual methamphetamine adsorbed onto various textiles, including cotton and polyester. This presents a significant route of exposure for small children, particularly due to mouthing behaviours as the authors did not assess airborne microfibres (Morrison et al., 2015). It is important to note that these residual levels of methamphetamine in the air were very low, on average one part per billion. The tendency of semi-volatile organic compounds to adsorb onto textiles means that even with such a low concentration in air, the dose ingested by toddlers, due to the mouthing of fabrics, was significant. In fact, it was found to be comparable to the therapeutic dose administered to individuals diagnosed with ADHD (Morrison et al., 2015). The authors developed a method to infer dose via ingestion. Identifying three important factors that influenced the exposure: the frequency of mouthing behaviour, the relative ability of the chemical to adsorb onto the surface of the material, and its solubility. The high solubility of methamphetamine means that almost all adsorbed residues would dissolve in saliva during mouthing (Morrison et al., 2015). Additionally, the same authors identified that textiles are a potential source of dermal exposure to phthalates, another semi-volatile organic compound (SVOC). They suggested that this pathway of exposure could be substantial while also highlighting the general lack of attention to this field of research (Morrison et al., 2015). Other SVOCs, such as pesticides and flame retardants, are yet to be investigated for exposure via textiles and fibres, although these compounds have been detected in household dust (Blanchard et al., 2014; Coakley et al., 2013; Harrad et al., 2008). Studies have shown that ingestion of household dust may be one of the primary pathways of exposure to pesticides and phthalates (Blanchard et al., 2014), flame retardants (Harrad et al., 2008), and even polychlorinated biphenyls (PCB), a highly toxic persistent pollutant (Coakley et al., 2013).

Summarising this evidence in light of the relative health risks of plastic versus non-plastic fibres, the evidence indicates that non-plastic microfibre may hold a greater concentration of contaminants, both added during manufacturing, such as formaldehyde and herbicide residues and adsorbed from the environment. Non-plastic fibres are more absorbent and with more physical imperfections (roughness) than plastic fibres, potentially increasing the likelihood of adsorption of chemicals from the environment meaning that chemical exposures may be higher from non-plastic fibres compared to plastic fibres (Morton and Hearle, 2008). The exposure via ingestion of microfibres is an important area for future study and should include consideration of the differences in chemical exposure between plastic and non-plastic fibres. Table 4 summarises the evidence regarding the chemicals associated with organic microfibers that could contribute to adverse health effects.

The following section will discuss the health impact of microfibres based on occupational epidemiology studies where exposure levels are high. However, it is important to note that health impacts from pollutants can occur even at low levels, as is seen with air pollution exposure). Over a wider population, could cause significant population-level harm. Therefore, the lack of evidence in non-occupational settings should not be interpreted as evidence that population-level exposure is safe.

Features of microfibres demonstrated to be important for health thus far include particle size, bio-persistence, and the type of fibre, as specific fibres pose different health risks and harm from any chemicals added to the fibre. Nevertheless, more research work is needed to explore all these features. Although this review primarily focuses on organic textile fibres, the assessment of health risks from microfibres has been influenced by the historical context of asbestos. We will begin by discussing this asbestos experience to understand current guidelines. We then discuss emerging evidence around the health impacts of organic microfibres and specifically address issues of bio-persistence, particle size and potential health risks associated with chemicals linked to microfibres.

3.3. *Asbestos fibres and their potential health risks*

Asbestos fibres were the first fibres identified as hazardous to human health. Epidemiologists describe three waves of asbestos-related illnesses. The first wave occurred, in the early 1900s among workers in asbestos mining, where the exposures were very high. The second wave took place from the mid-century to the 1970s, in manufacturing industries, where despite some protective measures, exposures remained lower, yet still significant. The third and current wave is affecting the construction and demolition industries, where asbestos products are broken up or damaged during removal or renovation (Boulanger et al., 2014), releasing bound fibres and hence generating exposure.

The hazards associated with asbestos are severe, causing chronic lung diseases including asbestosis as well as an, increased risk of lung, laryngeal and ovarian cancers along with mesothelioma, a diagnosis which is almost always terminal. The study of asbestos exposure has significantly influenced early occupational epidemiology related to fibre exposure (Donaldson and Tran, 2002). While it has been established that asbestos fibres are extremely harmful when inhaled, they appear to be harmless when ingested into the gastrointestinal tract (Greim et al., 2001). This explains the continued focus on the lungs as the primary concern for microfibre exposure. For example, when the WHO convened a workshop of experts in 2000 to attempt to define the “Toxicity of fibres and particles”, their focus was primarily on lung damage from inhalation (Greim et al., 2001). When developing a definition of a “microfibre”, the WHO based it on the respirable fraction –which refers to fibres that are small enough to enter the deep alveolar or air-exchange regions of human lungs.

“*Fibre dimensions established in the 1960s for the measurement of asbestos fibres are used to denote which fibres should be counted for occupational safety*” (World Health Organization, 2000).

Research continues to focus on inhalation, while mechanisms such as eye irritation and ingestion are reported less frequently, though they remain potential risk factors

3.4. Occupational epidemiology in textiles workers since the 2000 workshop

The decisions made in 2000 were a response to an immediate crisis regarding asbestos exposures which were still common at the time. Therefore, the factors considered relevant to the toxicity of fibres in the WHO 2000 “Workshop on the toxicity of fibres and particles” were based on findings related to inorganic fibres (Greim et al., 2001). Other evidence available at that time, from occupational health studies in textile manufacturing, was considered insufficiently reliable for drawing definitive conclusions and was therefore not included (Greim et al., 2001). Another factor influencing these decisions was the recent (to that period) improvements in exposure standards and ventilation regulations in many manufacturing settings. As a result, much of the earlier occupational health research was no longer considered relevant.

The review focuses on more recent epidemiological research from textile manufacturing, where we can assume levels of exposure to organic textile microfibres would be relatively high. Nevertheless, it must be emphasised that these are not microfibre studies, as such. Exposures considered in these epidemiological studies include airborne textile dust (Ali et al., 2018; Fang et al., 2013; Gallagher et al., 2015; Mastrangelo et al., 2002; Wright and Kelly, 2017), endotoxin (Fang et al., 2013) and chemicals including formaldehyde and other VOCs (‘T Mannetje et al., 2016). Perhaps the 2000 WHO workshop was, in part, why microfibres were not more specifically considered as an exposure of interest in these studies on textile workers.

Exposure to cotton dust from working in a cotton mill or preparing cotton textiles is associated with byssinosis, an occupational form of asthma. In 1978, the US regulated maximum allowable exposure levels and as a result, the levels of byssinosis have dropped in the US (Patel et al., 2024). However, in developing nations where cotton is produced, such as India and Pakistan, byssinosis remains prevalent among cotton workers (Ali et al., 2018; Daba Wami et al., 2018). Similarly, upper airway chronic conditions have been reported in workers in synthetic fibre production facilities in North America and the Netherlands (Wright and Kelly, 2017).

The relationship between occupational exposure to textile dust and cancers was examined in a 2002 meta-analysis which included seventeen occupational epidemiology studies (Mastrangelo et al., 2002). The authors found a pooled relative risk (PRR) for lung cancer incidence among workers at the start of the production line, exposed to raw, unwashed cotton dust of 0.77 (95 % CI. 0.69-0.86) and 0.71 (95 % CI. 0.56-0.85) in wool workers. Similar PRRs were observed across various job titles including, carders and fibre preparers, spinners and weavers (Mastrangelo et al., 2002). The protective effect associated with working with raw wool and cotton fibre dust in relation to lung cancer was attributed to endotoxin exposure associated with these raw fibres, and, in some of these occupational studies, endotoxin was measured at elevated levels. Endotoxins are fragments of bacterial cell walls, and exposure occurs due to the passive release of these chemicals due to bacterial cell wall deterioration. High levels of endotoxins have been implicated in the development of pulmonary illness in many occupational settings. However, evidence also suggests that lower exposure levels to endotoxin, such as is commonly found in farmers’ homes, may have a protective effect against the development of lung conditions, including asthma (Shamsollahi et al., 2019) and lung cancer (Mastrangelo et al., 2004).

In that same meta-analysis workers exposed to silk or synthetic fibres, who did not experience endotoxin exposure, did not show the same protective effect against lung cancer. In contrast, the incidence rates of sino-nasal cancer were elevated in workers exposed to cotton dust, including spinners and weavers who are further down the production line, not working with raw unwashed fibres, with a PRR equal to 4.14 (95 % CI 1.80-6.49) (Mastrangelo et al., 2002). For workers handling synthetic fibres or silk, the meta-analysis showed an increased risk of cancers of the digestive system with a PRR of 1.46 (95 % CI 1.10-1.82). Additionally, workers involved in dyeing had increased rates of bladder cancer with a PRR of 1.39 (95 % CI 1.07-1.71). The authors noted that in later studies conducted since the 1990s when improved ventilation and worker protections became more common, rates of these cancers declined, along with the apparent protective effect of the endotoxin for lung cancer (Mastrangelo et al., 2002). Endotoxin is associated only with raw, unprocessed cotton and wool fibres, and therefore, these findings suggest a potential protective effect cannot be transferred to the typical domestic setting, where exposure to the raw products is minimal.

Other studies are also consistent, indicating a range of increased cancer risks in textile workers, which may be associated with microfibre exposure. A 2016 meta-analysis of ten different occupational studies found an increased risk of Non-Hodgkin Lymphoma (NHL) in textile workers with over ten years of exposure including spinners, weavers and dyers, with an odds ratio (OR) of 1.85 (95 % CI 1.21-2.83) (‘T Mannetje et al., 2016). A long–term cohort study published results from 30 years of follow-up of female textile workers in Shanghai, China (Fang et al., 2013). This study reported an increased risk of death from gastrointestinal cancer in cotton workers with 20 years of exposure, showing a hazard ratio (HR) of 4.1 (95 % CI 1.8-9.7). In another study by Gallagher et al. (2015) from the same cohort, synthetic textile workers were found to have an increased hazard ratio for stomach cancer of 1.2 (95 % CI 1.1-1.4) (Gallagher et al., 2015). If microfibres are responsible for these increased cancer risks, it could be due to exposure via ingestion, rather than respiration. Ingestion of microfibres may occur when fibres are inhaled but are large enough to be captured and cleared by the mucociliary function. In this case, microfibres are pushed back up the larynx from the upper regions of the lungs and passed into the gastrointestinal tract (Burdett and Bard, 2006). As explored in the section on animal exposure to microfibres, there are significant impacts of microfibres on the gastrointestinal system.

Finally, to relate these findings to a domestic environment, numerous interventions aimed at asthma in the domestic setting have demonstrated improvements in asthma symptoms when they included more frequent house cleaning (Kanchongkittiphon et al., 2015). This suggests that reduced exposure to dust and/or fibres may contribute to better asthma outcomes in the general population. As observed in the occupational literature, the association of contaminants with asthma can be confounded by endotoxin exposure, which appears to provide a protective effect, particularly when exposed at a younger age (Shamsollahi et al., 2019).

3.5. Bio-persistence of microfibres

Bio-persistence is another crucial factor in determining toxicity from fibres, alongside size and exposure level (Greim et al., 2001). Researchers compared samples from the lung tissue near the tumour site with tissue from the tumour and then with tissue from tumours other than lung cancer from a separate group of patients. They found textile fibres, both cellulosic and plastic, in 87 % of the lung samples tested and in 99 % of the lung tumours. In contrast, tumours from other body sites did not contain fibres (Greim et al., 2001). Research is needed to understand whether these fibres could be causally associated with tumours, but this study at the least, demonstrates that organic fibres, presumably of textile origin, remain bio-persistent in human lungs, resisting immunological clearance.

In addition to remaining persistent in the lung, fibres may also resist degradation in the digestive tract. Hair is known to be resistant to digestion and can clump together, sometimes leading to an obstruction in the digestive tract of individuals who have continued ingestion, a condition known as a trichobezoar (Choi et al., 2010). The human body cannot break down cellulose through digestion, and phytobezoars - a collection or clump of plant fibres - are also well known, and generally ascribed to cellulose from dietary fibre (Park et al., 2022). Plastic fibres have also been demonstrated as bio-persistent, including in the gut (Wright and Kelly, 2017). Research has identified microplastics

Table 5
State of the evidence and research gaps for health impacts to humans from textile microfibres.

Topic	Subtopic	The current state of research	Specific research needs	Important evidence from this topic
Microfibres and human health		**Emerging**	Biological assays to understand current exposure levels.	Evidence of gastrointestinal and upper airway effects with exposure to textile microfibres.
	Health risks of asbestos/ inorganic fibres	**Mature**	Sufficient	This research is currently guiding WHO guidelines on microfibre exposure
	Occupational exposure in the production of microfibres	**Emerging**	Prospective studies with strong and repeated exposure assessment and, ideally, biological sampling is needed.	There is some good research, which needs replication.
	Bio-persistence of microfibres	**Absent**	What are the differences between plastic and non-plastic fibres in terms of bio-persistence and accumulation?	Microplastics found to collect in human organs including brain and placenta.
	Impacts of microfibre size	**Mature for inorganic fibres**	Sufficient.	This research underpins current WHO guidelines.
		Absent for organic fibres	It is very likely that the fibre sizes of health relevance for organic fibres differ from those of inorganic fibres. Research from animal studies is needed first.	Research shows that microplastic particles can enter the bloodstream and build up in organs. Similar research with fibres is needed.

accumulated in human brains (Nihart et al., 2025). Using electron microscopy for identification, researchers described accumulated particles as “nano-scale shard-like fragments” which were found at 7-30 times higher than the concentrations measured in the liver or kidneys (Nihart et al., 2025). Compellingly in this research, higher concentrations were found in the brains of those individuals who had died more recently (concentrations increased over time), and also in the brains of individuals who had died of dementia (Nihart et al., 2025). Microplastics in human placentas were found at approximately 3 particles per gram of placental tissue. Of these microplastics, fibres represented 22 % of particles identified, and “dominated the larger plastics (200-307 microns)”(Zhu et al., 2023), and the authors suggested that the transfer of microplastics from placentas to the foetal bloodstream was likely. These studies did not assess non-plastic particles or fibres.

Researchers assessed the potential for synthetic fibres to harm human health, concluding that there is potential harm to the general population from microplastic fibres from a physiological perspective; however, definitive conclusions cannot be made without a better understanding of exposure patterns (Wright and Kelly, 2017).

3.6. *Impacts of microfibre and the particle size*

The distinctions between particles and microfibres are important. It is widely considered that fibres may pose a greater risk to health than particles of similar mass (Donaldson and Tran, 2002). This is primarily because fibres have a much higher ratio of surface area to volume, allowing fibres to adsorb more chemicals than particles of similar mass (Donaldson and Tran, 2002). Additionally, fibres can interact with their environment in ways that particles cannot, tangling with each other to create obstructions. Furthermore, due to their shape, fibres may be able to pass through much smaller openings than particles of similar mass. For example, Wright and Kelly (2017) described how very small plastic fibres have the potential to pass through intestinal walls and enter the bloodstream or accumulate in other tissues (Wright and Kelly, 2017). Earlier research on mineral fibres also highlights the unique physicochemical properties of microfibres that enable them to cause more severe lung damage than non-fibrous particles of similar mass (Donaldson and Tran, 2002). These properties are discussed in more detail in the following sections.

3.7. *Health effects of coatings and treatments on microfibres*

Many treatments are applied to microfibres to enhance their appearance or physical properties. Many colouring agents and dyes can be highly toxic to humans and to the environment. Evidence from occupational epidemiology has indicated a link between prolonged exposure to textile dyes and an increased risk of bladder cancer (Mastrangelo et al., 2004). Dyes are chemically bound to the fibre, either through a direct chemical reaction or using a mordant as a coordination complex. This process provides the fabric with “colour fastness”, preventing the dye from washing out of the textile. As a result, dyes are generally inert by the time they reach the consumer. However, small amounts of unbound residual dye and other chemicals may remain, posing a non-negligible risk to human health from clothing, particularly through dermal exposure (Rovira and Domingo, 2019). Research into the health risks associated with clothing has demonstrated a complex mix of risks and protective effects of chemical exposure and researchers have called for more research (Licina et al., 2019). Table 5 summarizes the evidence regarding the potential adverse health effects of textile microfibre exposure.

4. Health effects of microfibres in animal studies

Studies of health effects in animals have arisen through the study of plastic pollution, and for this reason, most of these studies focus exclusively on exposure and health effects of plastics including microplastic fibres. Thus far, the health effects of microfibres have been researched, especially in fish and other aquatic animals. Current research indicates that these fibres are more harmful than other forms of plastic pollution such as particles, films and fragments.

4.1. *Microfibres versus microparticles (in animal studies)*

A meta-analysis of laboratory-based health effects studies in aquatic animals found that studies assessing the effects of microfibres were more likely to report adverse health effects than studies assessing non-fibrous microplastic particles (fragments or spheres) (Bucci et al., 2020). The meta-analysis reported that 62 % of studies investigating the effects of microplastic fibres reported adverse health effects, compared to 49 % of studies assessing the effect of micro and nano-plastic spheres and 21 % of studies on fragments (Bucci et al., 2020). Furthermore, health effects were detected at lower (particle number) doses than in similar studies involving fragments or spheres (Bucci et al., 2020).

Table 6
Summarising the state of the evidence of health impacts from microfibres in animals.

Topic	Subtopic	The current state of research	Specific research needs	Important evidence from this topic
Health effects of microfibres in animal studies		**Emerging**	What diameter of microfibres can pass through gut linings?	Initial studies do not show that non-plastic microfibres are less harmful than plastic fibres.
	Microfibres versus microparticles	**Emerging**	What differences exist in terms of internal mobility (passing through and collecting within internal organs) between microfibres vs microparticles and films?	Microfibres have been shown to move more slowly through animal guts than particles and films and to more strongly influence gut motility.
	Cellular impacts of microfibres	**Absent**	Can microfibres pass into or directly affect cellular function?	No current evidence.

This finding is supported by several other experimental studies that have compared health effects based on particle shape, consistently finding that fibres are more toxic than fragments or spheres (Au et al., 2015; Qualhato et al., 2023; Zhao et al., 2021). Au et al. found that microplastic fibres were more toxic to freshwater amphipods *Hyalella Azteca* than microplastic fragments ingested simultaneously. This toxicity was linked to the fibres taking longer to pass through the gut (Au et al., 2015). While plastic fragments passed through the gut at the same rate as nutritive food, fibres stayed longer in the gut, which the authors hypothesised was causally related to the slower growth rates measured in fibre-exposed amphipods due to interference with the digestive processes (Au et al., 2015). Similarly, a systematic review of studies of ecotoxicological health effects of plastic microfibres in aquatic environments reported that plastic microfibres accumulated in the digestive systems of aquatic animals (Qualhato et al., 2023).

Other adverse health impacts from microfibres, reported in aquatic animals, include dysbiosis (disturbance of the gut microbiome), reduced motility (weakened effect of gut muscles), damage to tissues of the digestive system and immune effects (Qualhato et al., 2023). One study showed that longer fibre lengths were associated with increased harmful effects, including greater bioaccumulation and reduced food intake (Zhao et al., 2021). All these studies focussed exclusively on plastic microfibres.

Only one study examined the health effects of non-plastic fibre ingestion in animals (Pittura et al., 2022). This study assessed the ingestion of polyamide, polyester and cotton microfibres by mussels. They revealed both differences and similarities in the health effects of these different types of fibre. All fibre types produced cellular (reduced phagocytosis) and chemical effects (reduced AOX enzyme), although timing and recovery varied. Recovery to fibre exposure was tested with a subsequent heat stress test. The negative immune effects of the polyamide were more severe in the shortterm, but recovery was quicker. For both polyester and cotton, the negative effects were more long-lasting. For all fibre types, reduced immune reactivity to subsequent heat stress compared to non-exposed controls was observed, possibly due to the reactive immunological pathways being already activated due to fibre ingestion (Pittura et al., 2022).

4.2. Cellular impacts of microplastics

Research examining the effect of microplastic particles at the cellular level has demonstrated that very tiny particles and fibres can slip between the cells of epithelial layers in the gut and skin, allowing them to enter other tissues. Within these tissues, particles can affect the immune system by causing inflammation, and reactive oxidation effects, leading to translocation and accumulation of particles in organs, including the brain (Wright and Kelly, 2017). The proinflammatory effects of microfibres are caused by the physicochemical properties of the fibres themselves. Adsorbed or inherent chemicals may drive oxidative responses, while fibres have been shown to resist immune clearance mechanisms (i.e. macrophage engulfment) due to their length, meaning the inflammatory response can be driven by both the shape (length) and biopersistence of the fibre (Greim et al., 2001). As discussed, the large surface-to-volume ratio of fibres compared to particles can mean that fibres exhibit higher toxicity because they can adsorb more chemicals relative to a particle of similar diameter (Donaldson and Tran, 2002; Singh et al., 2020). However, such adsorbed chemicals have not yet been identified in biological studies. There is evidence that particles and fibres may collect in organs, potentially affecting the expression of metabolites and hormones (Cedervall et al., 2012; Mattsson et al., 2015).

Research in animals, at the cellular level, has not typically differentiated between the effects of particles versus fibres, and importantly, levels of exposure in these lab-based studies have not always been representative of realistic environmental levels (Bucci et al., 2020). Addressing these gaps would significantly advance understanding of the health risks from environmental microfibres. Table 6 gives a summary of the potential health impact of microfibre exposure in animal studies.

5. Human microfibre exposure

In this section, we explore microfibre exposure. including its sources and current understanding of human exposure levels.

5.1. The size of the problem: fibre production and use in textiles

The amount of microfibre present in the environment is likely linked to the global production and usage of microfibre. This section highlights the magnitude of organic fibres produced globally and the variety of items they are used for, which can help us understand potential exposure pathways.

Over the past two decades, fibre production for textile use has been increasing at a rate of 3 % to 6 % per annum (MarketLine, 2017). This growth has resulted in a doubling of the annual production, rising from 58 million metric tonnes in 2003 (Burdett and Bard, 2006) to 109 million tonnes in 2020 (European Man-made Fibres Association, 2023). In contrast, production levels of non-plastic textile fibres have remained relatively stable over the last fifty years, with wool production reducing by around half over that time (MarketLine, 2017), while cellulosic fibre production has increased slightly. The main increase in fibre production is attributed to polyester, which now accounts for around 52 % of annual fibre production (European Man-made Fibres Association, 2023) and, along with other plastic fibres, makeup 60 % of global plastic production (Gasperi et al., 2018). This significant increase in polyester production, particularly over the last thirty years, has coincided with industrial advancements that allow for the creation of increasingly finer strands of polymer-based fibres (Burdett and Bard, 2006).

Clothing production has also experienced this growth, approximately doubling in the past 15 years (Changing Markets Foundation, 2017). This surge has sparked the "slow fashion" movement, which advocates for reuse and the purchase of more durable, less disposable products (Cataldi et al., 2013; Ellen MacArthur Foundation, 2017). However, the "fast fashion" industry does not fully account for the rise in textile consumption. Other notable increases in textile use can be found in agriculture and engineering, as well as the use of more polyester

Table 7
Percentage of the principal market for the main fibre types (%).

Use	Synthetic	Cellulosic	Cotton	Wool	**Total**
Clothing	42.6	10.9	32.9	13.9	100
Carpets	84.7	0.5	1.4	13.4	100
Domestic	42.1	12.3	42.2	3.4	100
Technical/Industrial	55.6	21.9	21.3	1.1	100
Tyres	39.4	59.3	1.3	0.0	100

Adapted from: Burdett and Bard, 2006. (Burdett and Bard, 2006)

insulation in construction.

Table 7 presents the four main categories of fibre (synthetic, cellulosic, cotton and wool) ranked by production volume and their respective applications. According to a report by S&P Global (Global, 2023) this ranking has remained relatively consistent from 2003 to 2023. Synthetic fibres continue to be the most widely produced fibre type, followed by cotton, cellulosic fibres, and wool.

5.2. *How are microfibres formed?*

Environmental organic microfibres are formed through the degradation of textiles and larger fibres. All common textile fibres consist of primarily fibrillar components held together with various types of chemical bonds. These chemical bonds present the weakest aspect in each of the various fibres, meaning that textile fibres break down into smaller and smaller fibres. This is true for protein-based (e.g. wool, silk), cellulosic, cotton and plastic fibres. Research has shown that both cotton and manufactured cellulose fibres are more prone to damage when wet than when dry, unlike non-cellulosic fibres (Bird, 1984). Wool, in particular, is susceptible to breakdown in alkaline environments, such as those produced by many laundry detergents (Cardamone, 2010; Vasconcelos et al., 2006).

These degradation characteristics may explain why high levels of non-plastic textile fibres are present in both airborne and aquatic pollution. Not only will non-plastic textiles break down more readily than plastics-based textiles, but also the individual fibres will degrade more quickly (Morton and Hearle, 2008). This might be why exposure assessment studies regarding the harmful effects of non-plastic fibres are lacking in the literature since these higher degradation rates also point to lower persistence in the human body. At the WHO workshop on the toxicity of fibres, the definition, based on resistance to biodegradation, suggests degradable fibres are not harmful to humans (Greim et al., 2001). However, this assumption that non-plastic textile fibres in the environment pose no harm –despite the extremely high levels observed is not well justified. In fact, given the high adsorption of chemicals during their production, manufacturing and laundering processes, it may be that natural fibres serve as a stronger vector of chemicals into the environment and food chain than more physically resistant plastic fibres (Morton and Hearle, 2008).

Plastics degrade with exposure to UV light, heat and cold (Ekvall et al., 2019). Some plastic fibres, such as nylon and amides (which includes Kevlar), exhibit a high resistance to degradation. However, these fibres tend to be low in softness. This increased resistance to degradation has led to the use of plastic fibres as reinforcing in wool and cotton textiles, by blending a proportion of strong plastic fibres into a yarn primarily composed of softer fibres, manufacturers create yarns which are a mix of plastic and wool or cotton, enhancing durability while maintaining the comfort factor of the natural fibres (Morton and Hearle, 2008). However, these manufacturing processes are complex. The successful development of methods to produce softer, warmer and more absorbent plastic fibres (Burdett and Bard, 2006) has resulted in a significant increase in the production of plastic polymer fabrics since the turn of the millennium. These softer plastic fibres are produced through a process that allows a single plastic fibre containing many smaller fibres within a sheath to be spun. Later in the manufacturing process, this sheath is destroyed, typically through brief exposure to high heat, leaving only the very fine fibres in the finished textile. Fabrics produced using these methods include coral fleece and sportswear textiles and have some of the finest fibres in textile manufacturing (Burdett and Bard, 2006).

Another important factor influencing fibre release from textiles is the fibre length. Textiles are woven from yarns, which are spun from individual fibres of varying lengths (known as staple). Shorter fibres tend to shed more easily during wear and laundering than longer fibres (Cesa et al., 2020; Morton and Hearle, 2008). Some fibres are too short to be spun into yarn and are instead used in non-woven textiles, such as those found in surgical masks and cleaning wipes, as well as in engineering textiles (Morton and Hearle, 2008). Even shorter fibres are used in flocks, which are often glued to surfaces to provide a fabric-like feel, such as in car upholstery, book covers and furniture items.

Recycled plastic fibres have been found to be more brittle than new plastic polymer fibres, making them more prone to breaking under mechanical and tensile forces (Morton and Hearle, 2008). This presents another important area for research, especially given the increase in the use of recycled fibres in textiles. The recycling of textile fibres aims to reduce plastic pollution; however, it may inadvertently increase fibre shedding due to the reduced wear properties - paradoxically leading to increased microfibre pollution.

5.3. *Where do they come from? Where do they go?*

Evidence of widespread contamination of the environment by microfibres has come from ecological studies, as has the increasing evidence for health impacts in animals (Browne et al., 2010; Pittura et al., 2022). However further research is needed to understand contamination pathways (Stanton et al., 2024; Weis et al., 2022). Part of the reason the contamination sources are unclear is that ecology studies have tended to focus on microplastics exclusively (Boucher and Friot, 2017; Magnusson et al., 2025), and contamination pathways were hypothesised to be related to the degradation of large volumes of plastic waste found floating in oceans and from tyre wear (Magnusson et al., 2025). However, it has become increasingly clear that the enormous quantities of microfibres cannot be accounted for via these pathways but must have a different source (Weis et al., 2022). More recently researchers have started to focus on the production and use of textiles, identifying wastewater as an important contamination pathway (Browne et al., 2011; Granek et al., 2022). However, recent work suggests that this may also not be the most important pathway (Napper et al., 2023), and, more research is urgently required to understand these contamination pathways (Weis et al., 2022), including the contribution directly from textile manufacturing (Stanton et al., 2024).

It is established that textile fibres are shed from clothing directly into the environment (Forster et al., 2023) during normal wear and laundering processes, contributing to microfibre pollution (Boucher and Friot, 2017). This will contribute to aquatic and airborne pollution, especially when wastewater sludge from treatment plants is sprayed onto agricultural land (Weis et al., 2022). Additionally, the heat and friction generated by clothes dryers are important contributors to microfibre release, both at home and in the environment (Kapp and Miller, 2020; O'Brien et al., 2020). Car tyre wear is also a significant source of microplastic pollution, and these microplastics can be transported large distances by air (Boucher and Friot, 2017). However, an initial assessment of air pollution from tyres suggests fibres are not released from their surrounding matrix (Panko et al., 2019). This indicates that while car tyres may contribute to microplastic pollution, they may not play a significant role in microfibre pollution, although more evidence is needed to confirm this. Other important pathways, such as the degradation of geotextiles used in agricultural and engineering situations, are yet to be thoroughly examined. Although geotextiles are typically buried to capture sediment or slow the natural movement of soil, they may become exposed due to erosion, particularly in sea walls or areas with unstable soils. These types of textiles are generally non-woven and degrade through abrasion (Morton and Hearle, 2008) or exposure to UV light.

A recent study aimed at identifying the primary source of microfibres in aquatic environments compared two pathways: release from wastewater and deposition from air. Surprisingly it found that the amount of fibre pollution from air deposition was several orders of magnitude higher than that from wastewater discharge (Napper et al., 2023). Another study detected high levels of microplastics contaminating snow in the Arctic, a remote alpine region and a more populated area in the Bavarian mountains in Germany (Bergmann et al., 2019). In this study, microplastic fibres only, were analysed separately from particles by colour. The authors hypothesised that the high levels of microplastics in snow may be attributable to the physical properties of snow, which allow it to more effectively capture fibres out of the air compared to water droplets (Bergmann et al., 2019).

Current methodologies are insufficient for confidently determining the sources of microfibres (Lusher and Primpke, 2023), and this should be a priority for future research. Promising work involving microfibre characterisation and spatial analysis, suggests that this approach may prove useful (Nematollahi et al., 2022). Future research aimed at understanding the pathways of microfibre pollution should consider factors such as size distribution, type (chemical composition) and colour, as this characterisation may provide valuable insights when considered alongside spatial distribution, as illustrated in a study in multiple centres across Iran (Nematollahi et al., 2022).

5.4. Evidence of textile microfibres indoors

Given indoor environments typically contain numerous textiles –used in clothing, furnishings, toys and cleaning tools - human exposure to microfibres is likely to be significantly higher in indoor environments than outdoors. Despite this very few studies have examined the prevalence of microfibres indoors, yet from the few studies that have been undertaken, important patterns have emerged. A study considering microplastics in indoor dust from Iran collected settled dust from 28 schools across the country. This study which isolated plastics from organic matter and then identified and counted the remaining microfibres using microscopy and counting software, finding that 99.7 % of microplastics in settled school dust were fibres (Nematollahi et al., 2022). A limitation of this study was the use of an optical microscope limited the counting to fibres bigger than 50 microns, which may underestimate the potential exposure load. The authors reported that the predominant type and colour of fibres varied across regions, suggesting that this characterisation could serve as identifying feature of the location (Nematollahi et al., 2022). Another study in Shanghai assessed microfibre deposition rates (from settled dust) in 42 restaurants and food outlets. Unsurprisingly, it found deposition rates were significantly higher during times of high foot traffic (due to constant resuspension of settled dust). The microfibres collected during opening hours at table height (using dining plates to simulate potential consumption exposure) consisted of 60 % cotton, and 32 % plastic types, with the remainder predominantly rayon (17 %) (Zhang et al., 2022).

Dris et al. (2017) measured airborne fibres in both indoor and outdoor environments (Paris, France). The researchers collected airborne fibres in four locations: two apartments, one office and one outdoor location, located by the monitored office. They found that the concentration of fibres in all three indoor settings was significantly higher than outdoors, with concentrations ranging from 1 to 60 fibres/m^3 (Dris et al., 2017). Of these fibres, 67 % were classified as “natural”, primarily cellulosic, while the remaining 33 % were plastic, with similar proportions in both indoor and outdoor measurements. Due to methodological limitations, the authors did not count fibres smaller than 50 microns (Dris et al., 2017). Most outdoor exposure assessment studies indicate a distribution pattern where smaller fibres are observed more frequently. This is likely due to the slower deposition rates of smaller particles, which allows the smallest particles and fibres to remain airborne longer and, therefore, travel further from the source (Wright et al., 2020).

O’Brien et al. (2020) demonstrated that mechanical clothes dryers significantly contribute to indoor airborne microfibres, estimating that typical domestic dryer use releases 3×10^3 fibres annually into indoor air (O’Brien et al., 2020).

This evidence raises the question, “Is indoor air a vector of microfibre pollution for the wider environment?” with initial testing of relative concentrations mentioned above, suggesting this may well be the case (Dris et al., 2017). Another important question that has yet to be answered is, “Has indoor exposure to microfibres changed in a way that is similar to outdoor exposure changes?” This question has not yet been explored, but understanding whether trends in the prevalence and characteristics of indoor microfibres mirror those found outdoors would help clarify the pathways of exposure.

5.5. Estimating human exposure to microfibres

Lepow et al. (2006), conducted a study to characterise “standard house dust” that could enhance objective testing of cleaning equipment. They assessed the dust from 34 homes across seven US cities, focusing on hard surfaces, rather than carpets. After separating out human and pet hair, they found that fibres, likely originating from textiles, typically make up 20–30 % of household-settled dust. These fibres were approximately 50 % synthetic and 50 % natural. Additionally, a separate hair fraction accounted for another 20–25 % of household dust, shared equally between human, cat and dog hairs (Lepow et al., 2006). Notably, the study focused on total fibres and did not specify the proportion that was respirable.

Dust ingestion has been estimated at 50 mg per day for adults, and 100–200 mg per day for small children, with the higher figure for children attributed to hand-to-mouth behaviours (USEPA, 1997). By combining these figures with the proportion of fibres in house dust (excluding hair), based on Lepow et al.’s estimates, we can estimate an annual load for adults based on the assumption that household exposure may be representative of exposure in general. These calculations suggest an annual adult load of fibres from dust ranging from 4.5 g to 5.5 g, while for children 1-4 years of age the annual load is estimated to be between 13.7 g and 16.4 g of fibres per year. If we consider a lifetime load (see formula below), using a lifespan of 70 years, with the first four at the mean child rate, we can suggest a conservative lifetime exposure estimate via non-purposeful ingestion (not including through dietary ingestion) of 0.4–1.2 kg of fibres, comparable to between a blouse and a pair of jeans. A better understanding of human exposure to microfibres in various environments will undoubtedly refine this initial estimate. Note that this calculation assumes that microfibres are a similar density to non-fibrous dust, and is summarised below:

$$E_L = 4\left(\frac{\delta}{100}.E_{Dc}.365\right) + (Age - 4)\left(\frac{\delta}{100}.E_{Da}.365\right)$$

Where:

$E_L = Lifetime\ exposure\ (grams)$

$E_{Dc} = Child\ daily\ exposure\ (grams)$

$E_{Da} = Adult\ daily\ exposure\ (grams)$

$\delta = Average\ percentage\ of\ household\ dust\ which\ is\ fibres\ (\%)$

The authors of the study conducted in Shanghai restaurants provided some valuable insights into the frequency of microfibre shedding based on the type of fibre and fabric. They found that materials with high hairiness and short-staple fibres contribute significantly to the release of microfibres into air (Zhang et al., 2022). Their estimates suggest that individuals could be exposed to approximately 200 microfibres per day,

Table 8
Summary of the state of the evidence for human exposure to microfibres.

Topic	Subtopic	The current state of research	Specific research needs	Important evidence from this topic
Human microfibre exposure		**Emerging**	What are current exposure levels to ingested microfibres in humans?	Exposure from airborne fibres is more significant than dietary exposure route.
	Global context	**Active**	What are the exposure pathways for organic microfibres?	Microfibres may travel enormous distances around the globe. Microfibres enter the environment via laundering and directly from shedding during normal activities.
	How are microfibres formed?	**Active**	Is there any effective way to stop textiles from shedding microfibres?	Some good research from pollution studies. What proportion of total microfibers this applies to is unclear since it focuses almost entirely on plastic microfibres.
	Source apportionment	**Emerging**	While a few studies exist, this has not yet converged as a major focus of research.	Research in microplastics is more mature, but it is unlikely that microplastic pollution has the same sources as most microfibre pollution.
	Indoor exposure	**Emerging**	Do textile microfibres adsorb more SVOCs than other dust compartments and, therefore, present as more health-relevant?	Initial studies suggest indoor exposure is generally higher than outdoors but needs replication.
	Estimating human exposure to microfibres	**Emerging**	Validated estimates of the makeup of textile microfibres as a proportion of house dust in different locations globally needed.	Very little information currently on textile microfibre exposure.
	Biological human exposure assessment	**Absent**	Blood and breastmilk samples are urgently needed.	Only one biological exposure study found with only 8 participants.

solely through consuming meals which have been exposed to microfibre fallout during preparation and consumption. Additionally, a separate study compared exposure to microfibres through diet (i.e. consuming mussels which have ingested microfibres), with exposure from airborne microfibre fallout. This study concluded that the airborne microfibres were by far the most significant source of microfibres in the human diet, estimating that this route accounted for between 13,000 and 68,000 microfibres per person per year (Catarino et al., 2018).

5.6. Biological human exposure assessment

A few studies on human exposure provide a more detailed perspective on human exposure patterns. For instance, a study by Brown et al. (2013) showed that respiration of fibres is probabilistic. Fibres with a diameter of up to about 20 microns may reach the pulmonary (air exchange) regions of the lungs, but this occurs with a low probability. However, for fibres at the 3 microns diameter cut point (which aligns with the WHO definition of a microfibre), 50 % of these fibres inhaled by adults would make it. In small children, the 50 % threshold for the respirable fraction is slightly larger, at 5 microns (Brown et al., 2013). Fibres which are inhaled but do not reach the pulmonary regions are collected in the mucociliary lining of the bronchial tubes and are then transported back to the larynx, where they are generally swallowed and ingested (Brown et al., 2013).

A very small exposure assessment study analysed human stools from eight participants across various countries to detect microplastic using FT-IR micro-spectroscopy. This study revealed that the microplastics found in the stool were predominantly polypropylene and polyethylene terephthalate, with a total of nine types of plastics detected. Most particles were fragments or films, while spheres and (plastic) fibres were less common (Schwabl et al., 2019). In another study, results from lung lavage samples from children with lung disease showed that 48 % of microplastics present were fibres. They did not specify the proportion of all particles which were fibres (Chen et al., 2023). Table 8 informs on microfibre exposure for humans. Biomonitoring needs to be expanded to include blood, breastmilk, urine and lung tissue samples of both plastic and non-plastic microfibres because only one study was found and only sampling stool.

6. Conclusions

Our review highlights that despite the ubiquitous presence of organic textile microfibres in the environment and the accumulating evidence for harmful effects on animals, there is a paucity of research on human health impacts from them. However, existing evidence from occupational studies of textile workers, where exposures are presumed high, shows gastrointestinal as well as upper airway effects, including cancer, are consistently found. This evidence, alongside increasing evidence of health harm in animals, suggests that the current presumption of a lack of health harm from these fibres does not appear to hold up to scrutiny.

The authors have here attempted to define the boundaries of, a new field of research, specifically: Microfibres. This field must, at least until evidence is developed to the contrary, include equal focus on plastic and non-plastic microfibres. Definitions for terminology should be based on health-relevant size and behaviour of microfibres which remain to be determined, so this research is most urgent. This research is needed to inform evidence-informed policy to prevent harm from microfibre exposure.

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CRediT authorship contribution statement

P. Taptiklis: Writing – review & editing, Writing – original draft, Resources, Methodology, Conceptualization. **M. Boulic:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **R. Phipps:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization. **H. Van Heerden:** Writing – review & editing, Writing – original draft. **C. Shaw:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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