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Short research paper

Capturing microfibers – marketed technologies reduce microfiber emissions from washing machines

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ABSTRACT

Microfibers are a common type of microplastic. One known source of microfibers to the environment is domestic laundering, which can release thousands of fibers into washing machine effluent with every wash. Here, we adapted existing methods to measure the length, count and weight of microfibers in laundry effluent. We used this method to test the efficacy of two technologies marketed to reduce microfiber emissions: the Cora Ball and Lint LUV-R filter. Both technologies significantly reduced the numbers of microfibers from fleece blankets in washing effluent. The Lint LUV-R captured an average of 87% of microfibers in the wash by count, compared to the Cora Ball which captured 26% by count. The Lint LUV-R also significantly reduced the total weight and average length of fibers in effluent. While further research is needed to understand other sources of microfiber emissions, these available technologies could be adopted to reduce emissions from laundering textiles.

1. Introduction

Researchers estimate that between 4.8 and 12.7 million metric tonnes of plastic waste enters the marine environment from land each year via mismanaged waste (Jambeck et al., 2015). This number does not include all sources of plastic to the ocean. For example, this estimate does not include microplastics (plastics < 5 mm in size) entering via wastewater, e.g., microfibers shed from textiles and microbeads from personal care products. Wastewater is presumed to be a large conduit for microplastics to reach the aquatic environment (Prata, 2018; Salvador Cesa et al., 2017). A better estimate of all sources, including via wastewater, is critical to inform effective policies to prevent further plastic pollution.

To inform effective policy, local municipalities, countries and regions seek scientific data on the effectiveness of proposed mitigation strategies for plastic pollution. For any proposed solution, it is useful to estimate its effectiveness. For example, researchers predicted that banning microbeads would prevent billions of microbeads from entering the environment via wastewater treatment plants (WWTP) daily in the United States (Rochman et al., 2015). Trash collection technology installed at river mouths (e.g., Mr. Trash Wheel in Baltimore, MD, USA) prevents plastic waste from entering large waterbodies. Mr. Trash Wheel, for example, has prevented 420 tons of trash and debris from entering Baltimore Harbor in its first 22 months of operation (Lindquist, 2016). Here, we aim to quantify the effectiveness of mitigation strategies aimed at preventing microfibers from textiles from entering the environment from one known source: washing machines.

Synthetic fibers (e.g. polyester, acrylic) have been used to produce textiles, including clothing, carpets, and furniture, for > 50 years (Geyer et al., 2017). Synthetic microfibers shed from these products can enter the environment as microplastics (Browne et al., 2011). As a consequence, microfibers are now found in habitats and wildlife around the world (Baldwin et al., 2016; Barrows et al., 2018; Lusher et al., 2014; Nelms et al., 2018).

Our focus is on proposed mitigation strategies for reducing microfiber emissions from laundry. Clothing, as opposed to other textiles made for applications like upholstery and home furnishing, is likely a large contributor because it is regularly washed. Although we do not yet know how microfiber emissions from washing machines compare to other sources (e.g., dryers, household dusting, manufacturing), we know that washing one garment in a washing machine can lead to the shedding of 100s to 1000s of microfibers, suggesting it as an important source (Browne et al., 2011; Hartline et al., 2016; Hernandez et al., 2017; Napper and Thompson, 2016; Pirc et al., 2016; Sillanpää and

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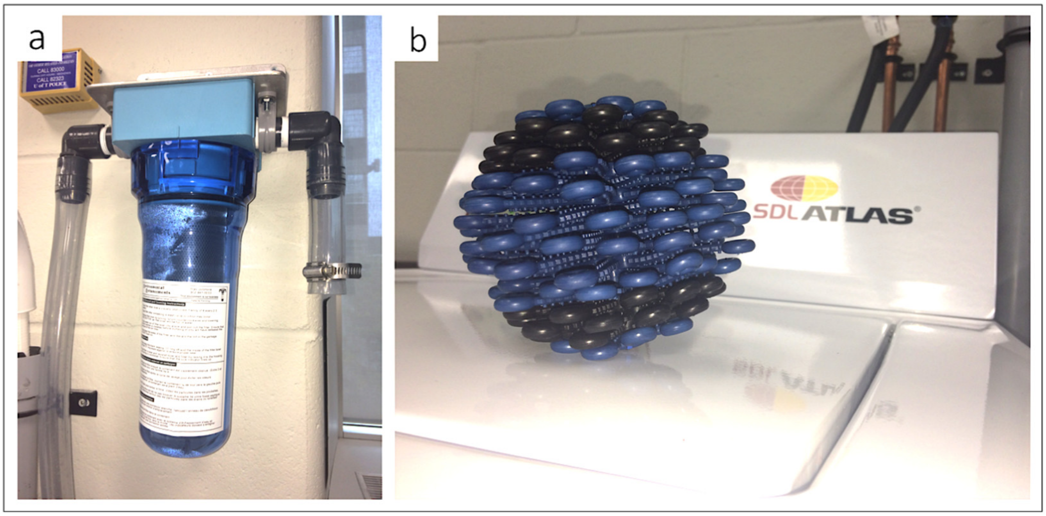

Fig. 1. (a) Lint LUV-R from Environmental Enhancements. (b) Cora Ball donated by Rachel Z. Miller of the Rozalia Project, on the SDL Atlas washing machine.

Sainio, 2017). Microfibers in washing machine water, or effluent, are either emitted directly into the environment or sent to municipal wastewater treatment plants (WWTPs). In a WWTP, microplastic removal into the sludge can be > 96% (Carr et al., 2016; Murphy et al., 2016). The fraction that remains in the effluent is emitted directly into the environment. The sludge is sometimes spread on agricultural land and from there can enter waterbodies via runoff (Zubris and Richards, 2005).

Once microplastics are released into the environment, they are extremely difficult to remove because of their small size. As such, it is worth exploring solutions to reduce their release to WWTPs in the first place, thus reducing their release to the environment. A proposed solution for preventing microfiber emissions from clothes washing is through the implementation of mitigation strategies in washing machines. In this study, we quantified the efficacy of two commercially available products sold for reducing fiber release from clothes washing, the Cora Ball and the Lint LUV-R filter (Fig. 1). To do this, we first adapted existing methods to quantify and characterize microfibers in washing machine effluent by count, weight and length. We then used this method to test the hypothesis that there would be less microfibers in washing machine effluent with the use of each technology than without.

2. Methods

2.1. Methods for the quantification of fibers in laundry effluent

Most studies have reported the weight of microfibers in washing machine effluent (Napper and Thompson, 2016; Pirc et al., 2016), rather than the count. We could not find any studies that report count, weight and length. Our first objective was to adapt existing methods to include count, weight and also length of microfibers in washing machine effluent. We were interested in length because mitigation strategies may target a particular size of microfibers (e.g., a filter with a specific mesh size) and because length may be an important metric when thinking about the environmental effects of the contamination. Our second objective was to use this method to quantify the difference in count, weight and length of microfibers in washing machine effluent when a fleece blanket was laundered with no technology, the Cora Ball or the Lint LUV-R filter.

2.1.1. Materials and supplies

For method development and experimentation, we used the same textile material: a 100% polyester fleece blanket (red IKEA Polarvide Throw). The mass and size of the blankets were 545 g and 129.5 cm × 170.2 cm, respectively. We chose polyester fleece due to its reportedly high shedding rate (Browne et al., 2011; Pirc et al., 2016; Sillanpää and Sainio, 2017). We chose red because it was a contrasting color on our filter paper and thus easier to quantify. It was also useful for quantifying contamination in the blanks.

We used an SDL Atlas M6 Vortex washing machine for method development and experimentation. This machine is a top loading machine. Based on the literature, top loading machines with a central agitator facilitate the shedding of more fibers compared to a front-loading machine (Hartline et al., 2016). We did not use any detergents or adjust temperature settings. Our primary objective was to simply quantify fibers with and without mitigation strategies. As such, we kept our washing parameters simple since we were not asking questions about differences under different washing conditions.

All laundry water filtering was conducted under a Clean Cell Laminar Flow hood with an additional plastic cover in front to protect our samples from contamination. A glass filter apparatus with a 47-mm filter holder and a stainless-steel Millipore filtration apparatus with a 142 mm filter holder were used for different steps in the process. All samples were filtered onto Whatman, Nuclepore Hydrophilic Membrane filters, 10 μm pore size, and 47 or 142 mm in diameter.

2.1.2. Count and length method

Our objective was to create a method where we could take a subsample from a homogenous sample to obtain a representative count and length of microfibers in washing machine effluent. Our methods were adapted from Hernandez et al. (2017). First, we created a sample by washing one fleece blanket using the settings described in Table S1. The fill level was set to 26.5 L (7 gal) with no rinse cycle. This volume of water was enough for the blanket to be completely submerged. After washing, the water was sampled from the back of the washing machine, using a clear plastic hose, and collected in a clean 30 L stainless steel stock pot.

After collection, the laundry water was homogenized using a clean glass stirring rod where extra stirring dispersed fiber clumps. Five subsamples were then collected from the homogenized effluent. First, an initial collection of ~250 mL of homogenized solution was transferred to a clean glass beaker. Using a clean glass volumetric pipette, and while stirring continuously with the clean glass rod, a 50 mL aliquot was subsampled. This was repeated five times. In total, five 50 mL aliquots were collected for each replicate. Using vacuum filtration, each aliquot was filtered onto a 10 μm polycarbonate filter.

Images were taken of each filter using a Leica M80 light microscope.

A 47 mm × 47 mm square of clear plastic was marked into 16 equal sections and used as a background. Image-J analysis was used to stitch images of the filter together with the grid/collection stitching plugin. This was followed by manual tracing of each red fiber with the segmented line tool + ROI manager (Fig. S1), to measure the length and number of all fibers on each filter. Fibers that were smaller than 100 μm were not quantified due to limitations of detection using ImageJ analysis. Microfiber counts were compared across subsamples to check for differences (using relative standard deviation) between subsamples with the aim of minimizing the relative standard deviation and thus ensuring we got representative samples that could be extrapolated to the volume of the effluent.

2.1.3. Weight method

The remaining laundry water (i.e., after the removal of the aliquots) was vacuum filtered onto a 142 mm 10 μm polycarbonate filter (Whatman, GE LifeScience, PA, USA) using a 142 mm Millipore vacuum filtration apparatus. The 10 μm polycarbonate filters were pre-soaked in RO water and dried at 55 °C for a minimum of 8 h to reduce variability in weight amongst the filters and from the procedure. After filtration, the filters and fibers were dried overnight at 55 °C in a clean glass petri dish. The filters were weighed immediately after removing from the oven on a Sartorius Entris Analytical Balance (with resolution down to 0.1 mg) before filtration and after filtration. Steady and reliable weights were obtained from the filters that held the bulk of the laundry water. Filters were enclosed in aluminum foil to protect them from contamination and were weighed three replicate times. The standard deviation of the three replicate weights for each filter was found to be orders of magnitude smaller than the mean (see Table S6). The small amounts of fibers filtered from the aliquots provided inconsistent weights that were not consistently greater than the drift of the balance. Because the weights of the fibers on the small filters were unreliable, the final weights of our samples do not include the fibers in the five 50 mL aliquots per sample.

2.1.4. QA/QC

To prevent procedural contamination, all glassware was washed with RO water and rinsed three times. We wore white cotton laboratory coats, and never wore red clothing. All filtering was done in the Clean Cell Laminar Flow hood, which was wiped down with RO water with a Kim Wipe each day before use. All laboratory tools were rinsed three times with RO water between each step to reduce cross contamination. Samples were covered with clean foil to prevent dust contamination. All filtered samples were kept in clean glass petri dishes at all times to prevent contamination from the lab. See Fig. S2 for a photo of the laboratory set-up. Lab blanks were taken 3 times (or after every 4th sample). During preliminary trials, 14 lab blanks were taken from the aliquoting procedure. In total, we sampled 17 lab blanks. At most, only one red fiber was found in a laboratory blank. Only red fibers were considered in this experiment.

2.2. Testing the efficacy of different microfiber-catching devices

2.2.1. Materials and supplies

We tested the differences in the number, weight and average length of fibers shed from one fleece blanket in washing machine effluent with no mitigation (control), a Cora Ball, and a Lint LUV-R filter. We ran four replicates for each of the three treatments (n = 4).

We tested the Cora Ball which consists of a plastic ball with many "arms" (donated by Rachel Z. Miller). We also tested the Lint LUV-R which has a stainless-steel mesh filter with a pore size of 150 μm in diameter. A new, clean Cora Ball was used for each wash because cleaning is tedious and requires picking fibers from between each arm (n = 4). The Lint LUV-R was cleaned between every use with RO water and a paper towel to remove all microfibers (n = 4).

2.2.2. Experimental design

To reduce the possibility of shedding rates changing with each wash, a new blanket was used for each replicate (n = 4) across all three treatments (control, Cora Ball, Lint LUV-R). After the wash cycle, all water was drained from the machine and collected in a clean 30 L stainless steel stock pot. For each sample, collection was followed by count and weight analyses, as outlined in Section 2.1.2. For the count analysis, the number of fibers (> 100 μm in length) were counted in each of the five aliquots. These numbers were then used to calculate an average (arithmetic) number of microfibers in 50 mL of effluent and then extrapolated to the count of fibers in the total effluent volume.

The individual replicates across all three treatments were performed in a random order through the use of a random number generator. After every 3 samples, a laboratory blank was run by running through an identical protocol without a fleece blanket. In total, 3 laboratory blanks were run and each were analyzed in the same way as experimental samples. To reduce cross-contamination, three empty cycles were run between every replicate (See Table S2 for washing parameters used for blank loads). See Section 2.1.4 for further details regarding QA/QC.

2.2.3. Data analysis

The differences in average total microfiber count per L of effluent, weight of microfibers in total effluent, and average microfiber length in subsamples across the three treatments (control, Cora Ball and Lint LUV-R) were compared using a 1-factor ANOVA (n = 4, $\alpha = 0.05$). We tested for homogeneity of variance using Bartlett's test. A post-hoc Tukey test ($\alpha = 0.05$) distinguished significantly different treatment means. We ran a 2-factor ANOVA with factors filter (5 levels) and treatment (3 levels) to ensure that the variation in number and length of fibers amongst 50 mL subsamples was less than the variation amongst treatments, and as a quantitative way to ensure that the standard deviation amongst subsamples was sufficiently small. Statistical analyses were run in R version 3.4.3.

3. Results

3.1. The method used for counting and measuring the length of microfibers

One of our goals was to adapt current methods to use three metrics of microfiber release according to weight (done on the total wash water minus ~1% used for subsampling), count and length (done on subsamples). Our subsampling method for analyzing microfibers in washing machine effluent by count and length enabled us to avoid counting and measuring individual microfibers in an entire effluent sample. As shown in Table 1, our protocol showed small relative standard deviations (i.e., < 20% relative standard deviation for count data, ranging from 3.6–17%) amongst 50 mL aliquot subsamples (See Table S3 for all data on count and length). Thus, although the volume of the aliquot was relatively small compared to the total effluent, we believe it is representative of the wash water.

3.2. Microfiber count in effluent

The control contained an average of 240 ± 38 (StDev) microfibers per 50 mL aliquot. The Cora Ball treatments contained 179 ± 30 microfibers and the Lint LUV-R treatments contained 32 ± 8 fibers. A 2-factor ANOVA testing for differences in the count of microfibers per subsample found a significant difference amongst treatments ($p < 0.0001$), and no significant difference amongst filters ($p = 0.3$) or a significant filter-by-treatment interaction ($p = 0.8$). This suggests that our subsampling method was sufficient to test our hypothesis.

3.3. Microfiber length in effluent

The average length of fibers (calculated as the arithmetic mean) per 50 mL aliquot of water was 1.4 ± 0.4 mm for the control,

Table 1
Average, standard deviation and relative standard deviation amongst the counts and lengths (mm) for the five 50 mL aliquot subsamples per replicate in our washing experiment.

Treatment	Replicate	Avg count	StDev	Relative StDev (%)	Avg length (mm)	StDev	Relative StDev (%)
Control	1	252	16	6	1.2	0.2	12
Control	2	181	6	4	1.2	0.1	12
Control	3	275	21	8	2.1	0.6	30
Control	4	253	25	10	1.2	0.1	8
Cora Ball	1	157	6	4	1.3	0.1	11
Cora Ball	2	177	13	7	1.3	0.2	11
Cora Ball	3	205	22	11	1.2	0.6	51
Cora Ball	4	175	20	11	1.3	0.1	5
Lint LUV-R	1	36	3	9	0.2	0.1	47
Lint LUV-R	2	40	5	13	0.5	0.2	43
Lint LUV-R	3	32	5	17	0.4	0.0	9
Lint LUV-R	4	21	3	15	0.5	0.1	19

1.5 ± 0.4 mm for the Cora Ball treatment, and 0.4 ± 0.1 mm for the Lint LUV-R treatment. We note that the length of fibers for the Lint LUV-R treatment are longer than the mesh size but their width allowed passage through the 150 μm mesh. A 2-factor ANOVA testing for differences in the length of microfibers per subsample found a significant difference amongst treatments ($p < 0.0001$), and no significant difference amongst filters ($p = 0.5$) or a significant filter-by-treatment interaction ($p = 0.5$). This again suggests that our subsampling method was sufficient to test our hypothesis.

3.4. Efficacy of mitigation strategies

3.4.1. Differences across treatments by count

Overall, we observed a significant reduction of microfibers by count for each mitigation strategy related to the control. The average number of fibers per L of washing machine effluent was calculated to be 3580 ± 390 when using the Cora Ball, 648 ± 165 when using the Lint LUV-R, and 4800 ± 820 with no mitigation strategy (Fig. 2; see Table S4 for all data). Statistical analyses showed significant differences across all treatments ($p < 0.0001$), with the fibers per L of effluent significantly lower in the Cora Ball ($p = 0.02$) and the Lint LUV-R ($p < 0.0001$) compared to the control.

3.4.2. Differences across treatments by weight

We observed no significant reduction of microfibers by weight with the Cora Ball compared to the control. We did observe a significant reduction of microfibers by weight between the Lint LUV-R and the control. The average total weight of fibers in mg/L of washing machine effluent was 1.89 ± 0.42 StDev when using the Cora Ball, 0.40 ± 0.09 StDev when using the Lint LUV-R, and 1.99 ± 0.45 StDev with no mitigation strategy (Fig. 3; See Table S5 for all data). The weight of fibers (mg/L) in effluent with the Lint LUV-R was significantly less than in the control ($p < 0.001$).

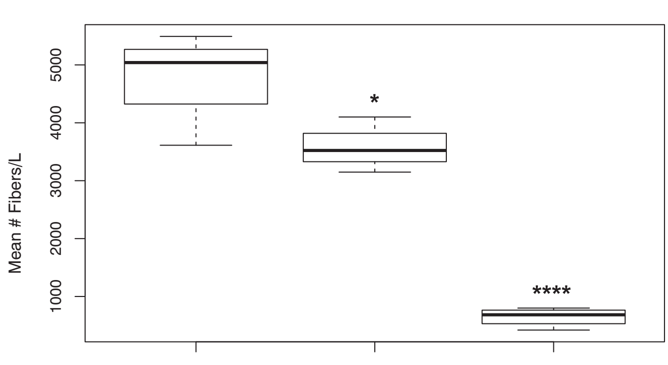

Fig. 2. Mean number of microfibers per L of washing machine effluent. One-factor ANOVAs showed a significant difference across all treatments ($p < 0.05$). A post-hoc test showed significant differences between both the Cora Ball and the Lint LUV-R compared to the control (*p < 0.05; **p < 0.01; ***p < 0.001; ****p < 0.0001). Boxes represent the first and third quartile, the line represents the median and whiskers represent the data range.

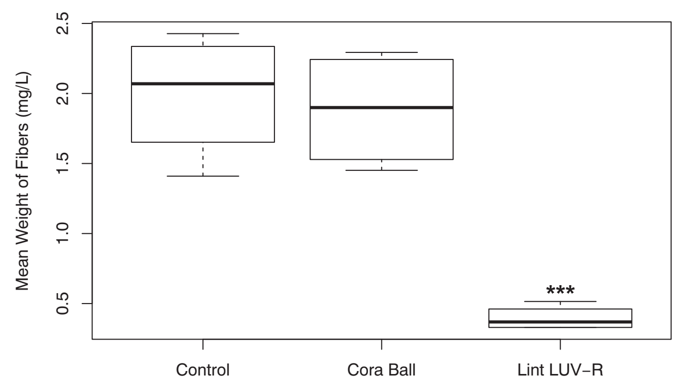

Fig. 3. Mean weight of microfibers in mg/L of washing machine effluent. One-factor ANOVA showed a significant difference across all treatments ($p < 0.05$). A post-hoc test showed significant differences between the Lint LUV-R and the control (*p < 0.05; **p < 0.01; ***p < 0.001; ****p < 0.0001). Boxes represent the first and third quartile, the line represents the median and whiskers represent the data range.

3.4.3. Differences across treatments by length

We observed no significant difference in microfiber length after washing with the Cora Ball compared to the control. We did observe a significant difference in the average length of microfibers between the Lint LUV-R and the control. The average total length of fibers (mm) in subsamples of washing machine effluent was 1.3 ± 0.1 when using the Cora Ball, 0.4 ± 0.1 when using the Lint LUV-R, and 1.5 ± 0.5 with no mitigation strategy (Fig. 4). Statistical analyses showed significant differences ($p < 0.001$), with the length of fibers in mm significantly lower in effluent from the Lint LUV-R ($p < 0.001$) compared to the control treatment.

4. Discussion

4.1. The method: counting, weighing and measuring microfibers

We adapted existing methods to enable researchers to quantitatively measure and characterize microfibers in bulk or total water samples using more than the single metric of weight. This method quantifies microfibers in washing machine effluent by count, weight and length. While methods to record the number and length of microfibers have been reported elsewhere (Hernandez et al., 2017), the application of the method described here is, to the best of our knowledge, the first to

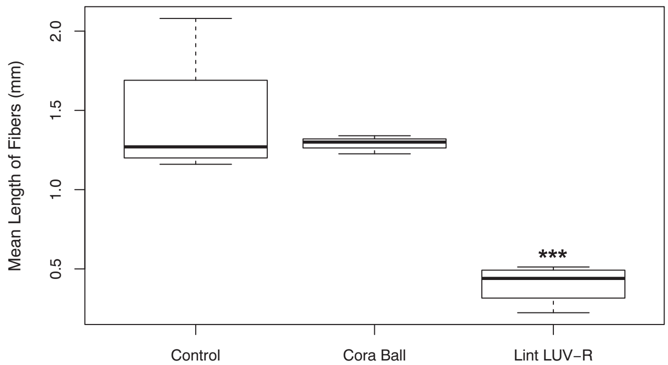

Fig. 4. Mean length of microfibers in mm in subsamples of effluent. One-factor ANOVAs showed a significant difference across all treatments ($p < 0.05$). A post-hoc test showed significant differences between the Lint LUV-R and the control (*$p < 0.05$; **$p < 0.01$; **$p < 0.001$; ***$p < 0.0001$). Boxes represent the first and third quartile, the line represents the median and whiskers represent the data range.

report microfiber emissions from washing machines by count, weight and length. The importance of having multiple metrics is to overcome the challenge of dealing with microfibers that are so lightweight, and as such, difficult to obtain reliable estimates of weight. It can be difficult to differentiate the signal from the noise, and especially for materials that shed relatively small weights of microfibers. In addition, we submit that understanding both size and count are important. They are useful metrics to be able to estimate exposure for animals, they are more comparable to what is most commonly reported in field studies (e.g. Lusher et al., 2013), and they can be used to determine concentrations of dietary exposure in lab experiments (Ziajahromi et al., 2018). Microfiber length also has biological relevance, since microplastic ingestion by different taxa has been shown to be restricted to certain sizes (Scherer et al., 2017).

4.2. Mitigation strategies reduce microfibers in the wash

Our results demonstrated that both the Cora Ball and the Lint LUV-R significantly reduced the number of microfibers in the wash. The Cora Ball and Lint LUV-R reduced the number of microfibers per L of effluent by an average of 26% and 87%, respectively.

By weight, we observed only a 5% reduction when using the Cora Ball versus an 80% reduction when using the Lint LUV-R. One possible explanation for these differences between technologies could be due to limitations in our method that excluded counts of fibers < 100 μm in length. The Cora Ball showed significant capture of fibers by count relative to the control, but not significant capture by weight. Since microfibers are very light-weight, a small reduction may be difficult to measure precisely on an analytical balance. Thus, counts likely capture differences between treatments more accurately than weight.

Compared to no mitigation strategy, we measured an 11% reduction in microfiber length when using the Cora Ball versus a 72% reduction in microfiber length when using the Lint LUV-R. The similarity in fiber length between the control and Cora Ball treatments suggests that the Cora Ball captures fibers over a wide range of lengths, while the lower average length found in the Lint LUV-R treatments indicates that fibers of greater lengths are captured. The Lint LUV-R reduced the mean microfiber length in the effluent by about 1 mm. The differences in length of microfibers for the Lint LUV-R treatment compared to the Cora Ball and the control were likely due to the mesh size of the filter built into the Lint LUV-R.

4.3. Policy implications

Available technologies to mitigate microfiber release from domestic washing machines can significantly reduce the amount of microfibers being emitted to WWTPs and/or the environment from washing our clothes. Although we do not yet know how washing clothing compares to other sources of microfibers released to the environment, our results point to the need—and the present opportunity—to mitigate releases from washing clothes.

As a case study, and to provide a simplified idea of the effectiveness of these mitigation strategies, we approximated the maximum potential for these control technologies to divert fibers from treated wastewater in a single region based on our findings. The City of Toronto has the largest population in Canada and is in the top 10 largest cities in North America. If we assume that 90,700 to 138,000 microfibers are shed into washing machine effluent per wash load (i.e., the range of particles per single fleece blanket in our study), and that the average household, out of 1,179,057 households in the City of Toronto (Statistics Canada, 2017), washes 219 loads per household per year (based on Natural Resources Canada, 2011), then we estimate that, based on our results, up to 23 to 36 trillion microfibers could be emitted to wastewater from washing machines each year in the City of Toronto.

Most of these fibers will travel with wastewater to a WWTP to be treated. Studies suggest that 83–99.9% of microplastics are captured in the sludge of a WWTP (Carr et al., 2016; Dris et al., 2015; Talvitie et al., 2017), with the remaining emitted to the aquatic environment via final effluent. If 99% of the 23 to 36 trillion microfibers are captured in the sludge, then up to 234 to 356 billion could be released directly into lakes and rivers annually based on our data and calculations. If the sludge is land applied, some of the remaining ~23–35.5 trillion could also be released into the environment.

If, on a municipal level, the Cora Ball or Lint LUV-R was placed into all households in Toronto, then the number of microfibers emitted into wastewater from washing machines could be reduced by up to 6 to 9 or 20 to 31 trillion fibers respectively each year based on our data. Assuming 99% capture in the sludge, this would translate to ~61 to 92 billion less microfibers going directly into the environment annually with the Cora Ball and 204 to 309 billion less microfibers going directly into the environment annually with the Lint LUV-R. Although this is a simple calculation based on assumptions of high release and capture rates, it demonstrates the potential effectiveness of a simple technology.

In terms of washing frequency, 219 wash loads per household per year is low compared to other studies in North America, which range from 315 to 442 (Golden et al., 2010; Lutz, 2005; Tomlinson and Rizy, 1998). People also often do mixed loads with several items in the washing machine at one time, versus with just one fleece blanket where the new blanket used was likely to shed relatively more fibers than other garments. Microfiber releases from other studies are 100–1900 (Browne et al., 2011) and 900–110,000 (Almroth et al., 2018) microfibers shedding per garment. In this study, we counted > 120,000 microfibers from a single small fleece blanket. This may be due to the top loading washing machine, or the textile material we used. The material was a new fleece blanket with unhemmed edges, which may contribute to the high fiber release. Sillanpää and Sainio (2017) suggested that microfiber release may be highest for new, unwashed garments. Thus, our estimates could be over- or under-estimates of microfiber release.

4.4. Limitations and future directions

Here, we evaluated microfiber capture in the wash by the Cora Ball and Lint LUV-R under specific wash conditions. We used one type of fleece blanket with long individual fibers. Microfiber capture may vary in a mixed load with garments that shed microfibers with different dimensions (e.g. length, width) and at different shed rates. For example, sportswear made from polyester may shed much shorter fibers that may not be captured as effectively by both technologies. Future work should focus on the efficiency of these mitigation strategies, and others, under various conditions and with different textiles. Furthermore, microfiber capture strategies could be evaluated from a consumer and behavioral perspective to explore the likelihood of adoption and how human actions may or may not facilitate the efficacy of these proposed strategies. For example, care and time must be taken to throw away the microfibers rather than rinsing them down the drain. In addition, a cost-benefit analysis may be conducted to determine whether the manufacturing of these products that capture microplastics outweigh the benefit of capturing microplastics, and whether it is more beneficial to use after-market technologies, or adopt technologies where filters are included in the washing machines upon manufacturing (i.e., akin to lint traps in dryers).

5. Conclusions

Using adaptations of existing methods, we demonstrated that the Cora Ball and Lint LUV-R reduced an average of 26% and 87% of the total number of microfibers (> 100 μm long) by count released from a new fleece blanket to laundry washing machine effluent, respectively. The Lint-LUV-R also significantly reduced the weight of fibers released but this was not the case for the Cora Ball. These results suggest that these two technologies added to washing machines could be an effective way to reduce microfiber emissions to the environment. While further investigations are needed to understand the relative contributions of microfibers from other textile products and their pathways to the environment, we know that textiles laundered in washing machines are one source of microfibers and that effective mitigation tools currently exist.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2018.12.012.

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