

## Efficacy of Face Masks Used in Uganda: A Laboratory-Based Inquiry during the COVID-19 Pandemic

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**Abstract.** With shortages of face masks being reported worldwide, it is critical to consider alternatives to commercially manufactured face masks. This study aimed to test and compare the efficacy of various makes of locally made or homemade cloth face masks obtained from face-mask vendors in Kampala, Uganda, during the COVID-19 pandemic. The testing was performed to assess the bacterial filtration efficiency (BFE), breathability, distance-dependent fitness, and reusability of the locally made or homemade cloth face masks, while considering the most commonly used non-published face-mask decontamination approaches in Uganda. During laboratory experimentation, modified protocols from various face-mask testing organizations were adopted. Ten different face-mask types were experimented upon; each face-mask type was tested four times for every single test, except for the decontamination protocols involving washing where KN95 and surgical face masks were not included. Among the locally made or homemade cloth face masks, the double-layered cloth face masks (described as F) had better BFE and distance-dependent fitness characteristics, they could be reused, and had good breathability, than the other locally made or homemade cloth face masks. Despite these good qualities, the certainty of these face masks protecting wearers against COVID-19 remains subject to viral filtration efficiency testing.

### INTRODUCTION

The CDC and the WHO endorsed the use of face masks as protective means to check the acquisition and spread of COVID-19.<sup>1,2</sup> Furthermore, unlike most authorities, the U.S. CDC advised that face masks should also be used by all in public settings as opposed to being used by only the sick.<sup>3</sup> The protective efficacy of face masks varies, and experimental data concerning the effectiveness of face masks in reducing infections in the community are remarkably insufficient and even contradictory.<sup>4–7</sup>

During this study's conception, global and local shortages of respirators and surgical face masks had been reported by various studies, shortages which were prompting the prolonged use or reuse of respirators and surgical face masks intended for single use<sup>8–11</sup>. Also, during the same time, the COVID-19 outbreak had sparked an important debate regarding the efficacy of face masks expressly the locally made or homemade cloth face masks.<sup>12–16</sup> The outbreak also exposed the inadequacy of existing guidelines with regard to the use of locally made or homemade cloth face masks generally used in low- and middle-income countries (LMICs), especially in Africa, where access to the imported commercially manufactured face masks is difficult, majorly because most of the populations cannot afford to acquire these face masks.<sup>12–16</sup>

Also, because of this, most of the populations in LMICs continue to explore non-published approaches to sustain a sufficient supply of face masks, including among others face-mask decontamination, which could prolong the wearable life of the face masks beyond their expiration dates and reducing the need to procure more costly respirators, for example, KN95.<sup>9</sup>

The labor-intensive and costly decontamination approaches published in several studies, for example, the use of vaporized hydrogen peroxide and ultraviolet germicidal irradiation, exacerbate the predicament for LMICs, promoting most of the populations to continue exploring non-published approaches to sustain a sufficient supply of face masks.<sup>8,17–19</sup>

Also, during this study's conception, Uganda had begun a phased approach of lifting the initially decreed countrywide lockdown.<sup>20</sup> At the time, the Ugandan government was also reviewing its policy on the mandatory use of face masks in public settings.<sup>20</sup>

Because of this, several untested makes of locally made or homemade cloth face masks, conceivably ineffective to protect wearers against acquiring COVID-19, swamped the Ugandan market, hence making it essential to assess the safety and fitness for use of the several makes of locally made or homemade cloth face masks that were commonly circulating on the Ugandan market during the COVID-19 pandemic.

With the hope of informing the development of policies regarding the use of locally made or homemade cloth face masks to prevent the transmission of COVID-19 in Uganda and other similar LMICs in Africa, this study aimed at testing and comparing the various makes of locally made or homemade cloth face masks obtained from face-mask vendors in Kampala, Uganda, during the COVID-19 pandemic; the testing was performed to assess the bacterial filtration efficiency (BFE), breathability, distance-dependent fitness, and reusability of the locally made or homemade cloth face masks, while considering the most commonly used non-published face-mask decontamination approaches.

### MATERIALS AND METHODS

**Study design and sites.** This was a laboratory-based descriptive study and was part of a larger study titled: Assessing knowledge, attitudes, perceptions, and skills towards the use

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of face-masks: a community-level perspective (MASKUG-2020) that aimed at testing and comparing various materials and forms of cloth face masks procured from face-mask vendors in Kampala, Uganda, during the COVID-19 pandemic. The study was carried out in the Department of Medical Microbiology at the School of Biomedical Sciences, College of Health Sciences, Makerere University, Uganda.

**Description and source of the face-masks studied.** Ten different types of face masks, each in quadruplicate, were purposively selected and procured from face-mask vendors in Kampala, Uganda's capital (Table 1 and Supplemental Data 6).

**Laboratory testing.** Four volunteers were engaged in the experiments as described in the Supplemental Files. Appropriately selected, internationally approved standard face masks (KN95) were also included as controls.<sup>21</sup> Semi-quantitative fitness testing for the test and KN95 face masks was performed using a procedure adapted from the 3M Center for Respiratory Protection (the United States).<sup>33</sup> The 3M procedure was modified to include the number of squeezes required for the volunteers to taste the saccharin reagent. This procedure was again modified to include testing at 2, 3, 4, 5, and 6 m to achieve the distance-dependent fit testing as described in Supplemental Data 1 and 2.

Bacterial filtration efficiency of the KN95 and the test face masks was determined using an in-house method where a stream of 0.5 McFarland *Mycobacterium smegmatis* aerosols was generated using a handheld sprayer and directed through the face masks onto the 7H11 agar plates using a vacuum pump. All this was performed in a decontaminated biosafety cabinet as described in Supplemental Data 3. The BFE was determined by counting the number of colony-forming units on the test culture plates compared with those on the positive control culture plates. The breathability of the positive control and each type of test face mask was carried out using a procedure adapted from the ASTM E96 (ASTM International, West Conshohocken, PA) desiccant method where anhydrous

calcium chloride granules were almost filled in the glass beaker, covered with the face masks, and the difference in weight measured after being left at room temperature. The environmental temperature and humidity of the room were monitored and recorded as described in Supplemental Data 4. In-house reusability was performed for each face-mask type by repeating all the aforementioned procedures after 1) each type of surgical, positive control, and cloth face masks were sprayed with 70% ethanol and dried under the sun; 2) each cloth face-mask type was washed with a nonbacterial soap and dried under the sun; and 3) each cloth face-mask type was washed with a nonbacterial soap, dried under the sun, and ironed as described in Supplemental Data 5.

**Data management and analysis.** Data from the laboratory collection forms previously validated by the study principal investigators and the laboratory team were entered, cleaned, and analyzed using Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA) and STATA 14.0 statistical software (StataCorp, College Station, TX).

1. Bacterial filtration efficiency of the face masks tested. This was calculated using the formula:

$$= \frac{\text{Positive control (cfu)} - \text{Mean Test plate (cfu)}}{\text{Positive control (cfu)}} \times 100 = \text{BFE}, \text{ to identify the \% microorganisms that had penetrated through each mask material and results presented in Table 1. The mean and SD of the masks at each treatment method were calculated in STATA 14.0 (StataCorp) and presented in Table 1.}$$

2. In-house breathability testing of the face masks. To determine the average weight increase, the increase in the weight of the beakers in each of the experiments was added and divided by the number of experiments performed as per the formula below:

$$(\text{wt1} + \text{wt2} + \text{wt3} + \text{wt4})/4 = \text{Average weight increase.}$$

The average weight increase was then plotted as shown in Figure 1B, in the following text, to identify the mask with the highest breathability.

TABLE 1  
Bacterial filtration efficiency of the face masks

Type/description of face mask	Mask BFE (%)					NDA* approved	GOU† approved
	No decontamination	70% ethanol	Washed and dried under the sun	Washed, dried, and ironed			
A- Single-layer polypropylene with elastic straps	≥ 99.9	≥ 99.9	≥ 99.9	–		No	No
B- Single-layer thick material with thick elastic straps	≥ 99.9	≥ 99.9	≥ 99.9	≥ 99.9		No	No
C- Single-layer thick material with single elastic straps	≥ 99.9	≥ 99.9	≥ 99.9	≥ 99.9		No	No
D- Double-layered with kitengi on the outside, and cotton on the inside	≥ 99.9	≥ 99.9	≥ 99.9	≥ 99.9		No	No
E- Single-layer kitengi with elastic straps for attaching around ears	≥ 99.9	≥ 99.9	≥ 99.9	≥ 99.9		No	No
F- Double-layered cloth nonelastic straps for tying around the head	≥ 99.9	≥ 99.9	≥ 99.9	≥ 99.9		No	No
G- Surgical mask bought from a pharmacy	≥ 99.9	≥ 99.9	–	–		Yes	Yes
H- Surgical mask bought from street	≥ 99.9	≥ 99.9	–	–		No	No
I- Face scrub cloth with elastic straps for attaching around ears	≥ 99.9	≥ 99.9	≥ 99.9	≥ 99.9		No	No
J- Thick material with a single elastic strap for tying around the head	≥ 99.9	≥ 99.9	≥ 99.9	≥ 99.9		No	No
K- KN95 face mask	≥ 99.9	≥ 99.9	–	–		Yes	Yes
Mean (SD)	≥ 99.9 (± 0.0)	≥ 99.9 (± 0.0)	≥ 99.9 (± 0.0)	≥ 99.9 (± 0.0)		–	–

BFE = bacterial filtration efficiency.

\* Uganda National Drug Authority.

† Government of Uganda.

- Distance-dependent fitness testing of the face masks. Data on distance-dependent fitness was analyzed in Excel, where it was described and presented as graphs as shown in Figure 2.

**Ethics approval and consent to participate.** Ethical approvals were obtained from the<sup>1</sup> School of Biomedical Sciences-Research and Ethics Committee, College of Health Sciences, Makerere University (approval number: SBS-793), and the Uganda National Council for Science and Technology (approval number: SS489ES). Written informed consent was obtained from each of the study volunteers before performing the laboratory investigations.

## RESULTS

### Bacterial filtration efficiency of the face masks tested.

All the face masks that had been tested had a BFE of  $\geq 99.9\%$ , regardless of the face-mask decontamination method used (Table 1).

**In-house breathability testing of the face-masks.** There was a significant increase in the average weight of the beakers containing desiccant and sealed with face masks A-J after the 24-hour duration of the testing. Notably, the glass beakers containing the desiccant that had been sealed with the face-mask H had a significantly higher mean weight gain than the other face masks, whereas face-mask F had a significantly higher mean weight gain than the other face masks tested, regardless of the face-mask decontamination method used (Figure 1).

### Distance-dependent fitness testing of the face masks.

Figure 2 shows the relationship between the average number of sprays to tasting saccharin with distance, as the measure for distance-dependent fitness testing of the face masks.

**Face-mask testing without decontamination.** At 1 m, the study volunteers wearing face-masks A, B, C, D, E, F, G, H, I, and J tasted saccharin after an average of 17, 6, 40, 17, 9, 11, 10, 5, 33, and 11 sprays, respectively. The average number of sprays required to taste saccharin then increased with an increase in the distance. The average number of sprays until saccharin was tasted for face-masks G and H increased

exponentially to  $\geq 500$  at 2 m, whereas that for face-mask F increased steadily to 2 m at which point they increased exponentially, surpassing the 500-spray mark at 3 m. Also, the average number of sprays until saccharin was tasted for face-mask J increased steadily to 5 m at which point they surpassed the 500-spray mark, whereas that for the face-masks A, B, C, D, E, and I increased steadily to 6 m but did not surpass the 500-spray mark. So, face-masks G and H passed the distance-dependent test at 2 m, whereas mask F and J passed the same test at 3 and 6 m, respectively. All single-layered face masks did not pass for a distance-dependent fitness test. Furthermore, with the KN95 face mask, saccharin was not tasted at any distance after up to 500 sprays, thus not including its findings in the figure (Figure 2A).

**Face-mask testing after decontamination with 70% ethanol.** At 1 m, the study volunteers wearing face-masks A, B, C, D, E, F, G, H, I, and J tasted saccharin after an average of 4, 6, 5, 6, 4, 11, 5, 4, 8, and 11 sprays, respectively. However, the average number of sprays required to taste saccharin then increased with an increase in the distance. The average number of sprays until saccharin was tasted for face-mask F increased steadily to 2 m at which point they increased exponentially surpassing the 500-spray mark at 3 m, whereas those of face-mask I increased steadily to 5 m at which point they then increased exponentially also surpassing the 500 spray-mark at 6 m. Therefore, on decontamination with 70%, face-masks F and I passed the distance-dependent fitness test. Noteworthy, the face-masks G and H failed the distance-dependent fitness test. Furthermore, with the KN95 face mask, saccharin was not tasted at any distance after up to 500 sprays, thus not including its findings in the figure (Figure 2B).

**Face-mask testing after washing of face masks with a nonbacterial soap and drying them under the sun.** At 1 m, the study volunteers wearing face-masks A, B, C, D, E, F, I, and J tasted saccharin after an average of 3, 4, 2, 7, 5, 6, 6, and 4 sprays, respectively. However, the average number of sprays required to taste saccharin then increased with an increase in the distance. The average number of sprays until saccharin was tasted for face-mask F increased steadily to 3 m at which point they increased exponentially till they surpassed the 500 spray-mark at 4 m, whereas for face-mask I, they increased to

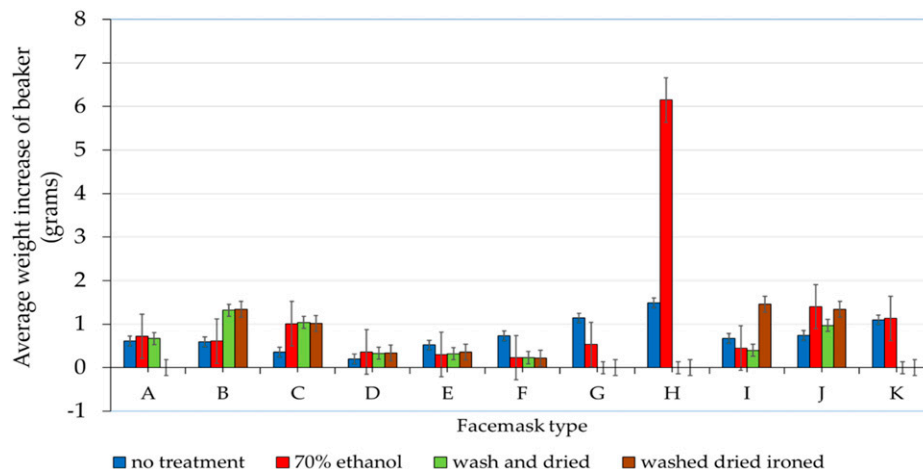


FIGURE 1. Average increase in weight of beakers containing the desiccant sealed with the face masks (A–J), when not treated (blue), after treatment with 70% ethanol (red), washing and drying (green), and washing, drying, and ironing (maroon). The error bars represent the SD of the data sets. This figure appears in color at [www.ajtmh.org](http://www.ajtmh.org).

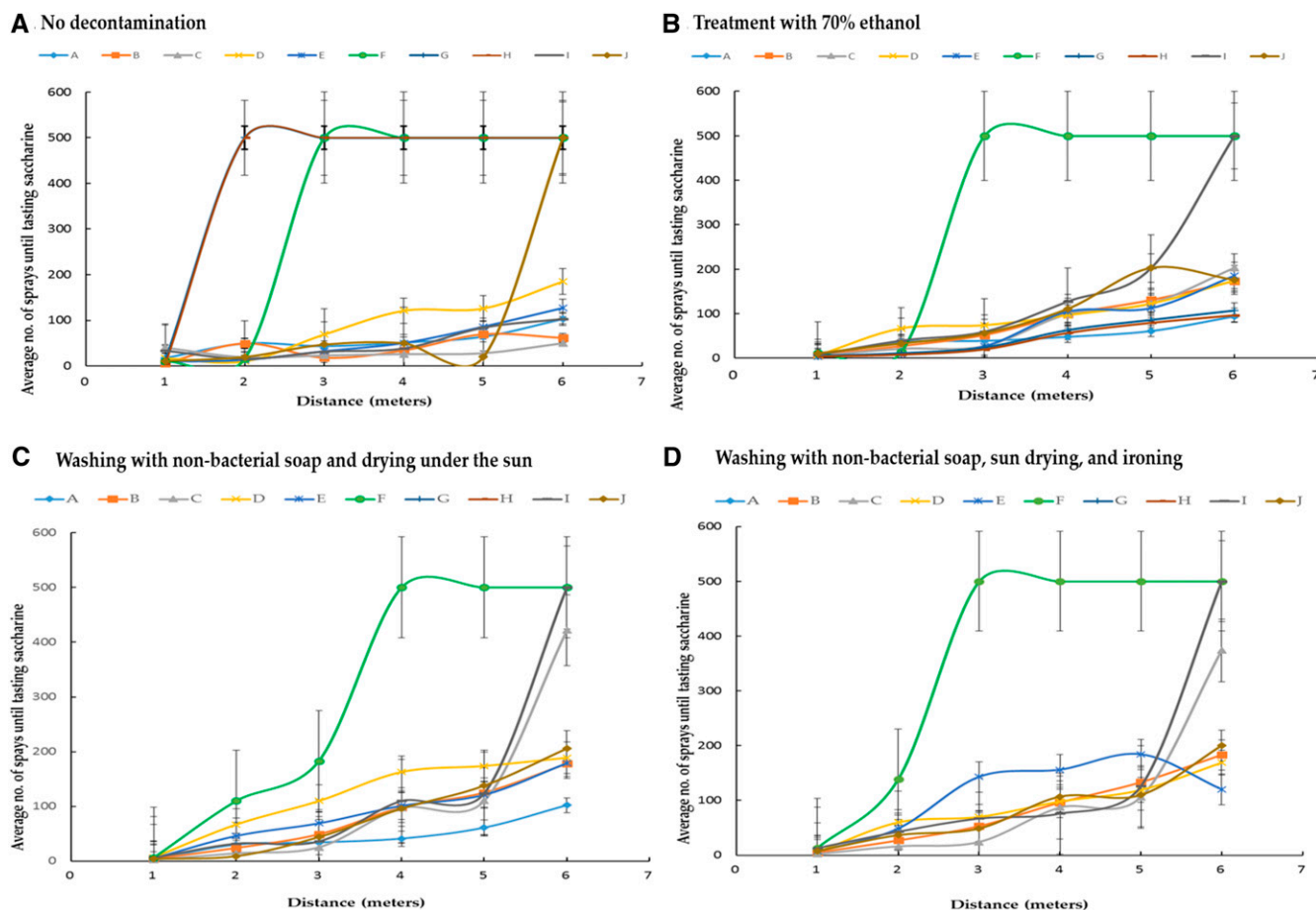


FIGURE 2. Distance-dependent fitness testing of the face masks with different treatment measures. Trends of the sensitivity of saccharin solution with the increase in distance from the participants (volunteers) wearing face masks, without treatment (A), after decontamination with 70% ethanol (B), after washing the face masks with a nonbacterial soap and drying them under the sun (C), and after washing the face masks with a nonbacterial soap, drying them under the sun, and ironing them (D). The error bars represent the SD of the data sets. This figure appears in color at [www.ajtmh.org](http://www.ajtmh.org).

5 m at which point they then increased exponentially surpassing the 500 spray-mark at 6 m. Therefore, on washing the face masks with a nonbacterial soap and drying them under the sun, mask F and mask I passed the distance-dependent fitness test. The KN95 face mask could not be used in this set of experiments, and hence the absence of its findings in the figure (Figure 2C).

**Face-mask testing after washing of face masks with a nonbacterial soap, drying them under the sun, and ironing them.** At 1 m, the study volunteers wearing face-masks A, B, C, D, E, F, I, and J required an average of 5, 2, 6, 7, 13, 13, and 8 sprays, respectively. However, the average number of sprays required to taste saccharin then increased with an increase in the distance. The average number of sprays until saccharin was tasted for face-mask F increased steadily to 2 m at which point they increased exponentially surpassing the 500 spray-mark at 3 m, whereas for face-mask I, they increased steadily to 5 m at which point they increased exponentially surpassing the 500 spray-mark at 6 m. Therefore, on washing the face masks with a nonbacterial soap, drying them under the sun, and ironing, face-masks F and I passed the distance-dependent fitness test. The KN95 face mask could not be used in this set of experiments, and hence the absence of its findings in the figure (Figure 2D).

## DISCUSSION

To the best of our understanding, this is the initial study assessing the efficacy of homemade cloth face masks in Uganda. We found that locally produced double-layered cloth face masks have properties suggesting appropriate protection against SARS-CoV-2 transmission, potentially allowing use of these masks, rather than more expensive surgical face masks or respirators, to help control COVID-19 in LMICs.

This study's finding where surgical face masks obtained from the community pharmacy or street vendors had sufficient BFE and more reliable breathability than any other type of locally made or homemade cloth face masks that had been tested is consonant with the findings of related studies.<sup>22-24</sup> These studies alluded to the effectiveness of surgical face masks in offering protection against infectious aerosols, for example, SARS-CoV-2, attributing this to their excellent qualities of BFE and breathability. This finding is contradictory with those of other studies.<sup>25-27</sup> These studies stated inefficiencies in BFE of surgical face masks, inefficiencies which likely negatively affect the ability of these face masks to offer protection against infectious aerosols. However, various observational studies have found no notable advantages of other respirators, for example, KN95 over surgical face masks. They

have also indicated the ability of these face masks to not only offer protection against infectious aerosols like SARS-CoV-2 but also offer a cheaper alternative to the other respirators, for example, KN95, which have been reported to offer better protection than the surgical face masks.<sup>9,22,28–30</sup> Therefore, notwithstanding the shortcomings of surgical face masks, there remains a reason for optimism concerning their real-world effectiveness.

The variances in performance of the surgical face masks that had been obtained from the community pharmacy and the street vendors reported in this study could have been due to the different materials and/or the make of these face masks. This thinking has also been documented in a related study.<sup>31</sup> In this study, surgical face masks by different manufacturers were reported to provide diverse levels of protection to wearers.

The findings of this study that point toward decontamination of surgical face masks obtained from the street vendors using 70% ethanol, likely negatively affecting the general efficacy of these face masks, could have been due to the 70% ethanol damaging not only the structural integrity of the surgical face masks but also other characteristics of the face masks, for example, the hydrophobicity, a thought that has also been shared in related studies.<sup>11,21,32</sup>

The findings of this study in which locally made or home-made, double-layered cloth face masks were found to have good breathability, BFE, and the potential to be reused following several non-published decontamination approaches could be related to those of related studies,<sup>5,33</sup> in which face masks that had been made from two layers of quilt fabric with household paper towels as filters were reported to be viable alternatives to surgical face masks and other respirators such as KN95 and N95. Although these studies recognized the supremacy of surgical face masks over cloth face masks, they highlighted that the use of a cloth face mask was several-fold more effective than not wearing a face mask at all.

As the world, in particular LMICs standing to benefit the most,<sup>18</sup> seek ways of prolonging the wearable life of face masks and reducing the need to procure more costly respirators, this study identified locally made or homemade, double-layered cloth face masks with reusable potential, following different non-published but commonly used decontamination approaches. Also, similar to the findings of related studies,<sup>34,35</sup> this study informs local mass production of cloth face masks, by small-scale enterprises using low-cost and locally available resources to ensure the widest availability and use of face masks to prevent the acquisition and spread of COVID-19.

Our study had some limitations. First, the study used *M. smegmatis* as a pathogen in the BFE testing; this organism is 3- to 5- $\mu$ m long, whereas the recommended *Staphylococcus aureus* is 0.5- to 1.5- $\mu$ m long, and the SARS-CoV-2 virion is 50- to 200-nm long. Second, the study was unable to pursue viral filtration efficiency (VFE) testing. Hence, it is uncertain whether results based on *M. smegmatis* are relevant for protection against viral pathogens. Third, automated aerosol generation was not possible, and so this study used handheld sprayers for aerosols. Fourth, although we measured temperature and humidity during assays, the wind speed was not measured, and this may have affected aerosol transmission.

The study identified locally made or homemade double-layered cloth face masks (face masks described as F) that had

good breathability, BFE, and could be reused, in attempts to protect against infectious aerosols of SARS-CoV-2. Further advancements in the design of such face masks to resemble surgical and KN95 face masks and testing including VFE could inform the reliability of the use of these face masks in protecting wearers against COVID-19. These face masks could also serve as cheaper alternatives for populations in low-income settings where access to surgical face masks and other respirators such as KN95 is limited.

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