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Evaluation of expelled droplets through traditional Islamic face coverings

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BACKGROUND: Expelled droplet count is an important factor when investigating the efficacy of face coverings since higher droplet counts indicate an increased possibility of disease transmission for airborne viruses such as COVID-19. While there is some published work relating facemask style to expelled droplet count during speech, there is no published data regarding the effectiveness of traditional Islamic face coverings such as the ghutra and niqab commonly worn by men and women in the Arabian Peninsula.

OBJECTIVES: Measure the effectiveness of worn traditional Islamic face coverings in reducing expelled droplet count during speech.

DESIGN: Experimental study

SETTING: Biomedical engineering department at a university in Saudi Arabia.

MATERIALS AND METHODS: Using a previously described low-cost method for quantifying expelled droplets, this study compares droplet counts through commonly worn traditional Islamic face coverings and conventional three-ply surgical masks worn during speech. The device records scattered light from droplets (>5 μm diameter) as they pass through a laser light sheet (520 nm), and then video processing yields droplet counts.

MAIN OUTCOME MEASURES: Percent reduction in the number of expelled droplets passing through face coverings during speech compared to no face covering

SAMPLE SIZE: 9-15 recorded samples per face covering (n=3) plus no face covering control (n=1) in three females.

RESULTS: The average percent reduction for each mask type compared to no mask trial was 76% for the cotton ghutra, 93% for the niqab, and 95% for the surgical mask. The niqab and ghutra had relatively high variability in droplet reduction.

CONCLUSIONS: Traditional Islamic face coverings block some expelled droplets, but at lower rates than surgical masks. High standard deviations within facemask groups with high variability in fit (i.e., the cotton ghutra) further denote the importance of fit in face covering effectiveness. Some protection from airborne viruses is likely with traditional Islamic face coverings compared to no mask, but the amount of protection depends on the fit of the face covering.

LIMITATIONS: Detectable droplets limited to particles greater than 5 μm diameter with forward expulsion direction.

CONFLICT OF INTEREST: None.

The transmission of coronaviruses, such as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and Middle East respiratory syndrome-related coronavirus (MERS-CoV), that lead to respiratory diseases is predominantly via respiratory droplets from infected individuals or by coming in contact with contaminated surfaces.[1,2] Droplets are released into the air at a short distance of <1 m after an infected individual coughs, sneezes, or speaks, and the virus infects the susceptible host after it is transferred to the mucous membranes of the eyes, nose, or mouth.[1]

Several studies indicate that SARS-CoV-2, the virus causing coronavirus disease 2019 (COVID-19), spreads through airborne transmission over both short and long distances as droplets evaporate into small aerosol particles.[1,3] Similarly, MERS-CoV is mainly transmitted through direct contact and aerosol particles.[4] During the 2015 MERS outbreak, MERS-CoV was detected in air samples and on distant surfaces, suggesting that transmission is both airborne and via respiratory droplets.[5]

Large and small droplets contribute differently to the transmission of the disease. The primary mode of human-to-human transmission of SARS-CoV-2 is known to be triggered by close contact with an infected individual and their respiratory droplets during coughing, sneezing, and other respiratory behaviors that create large droplets (>5 μm diameter).[6] Transmission through smaller droplets or respiratory aerosols (<5 μm diameter) created by speaking, humming, screaming, or breathing is also considered an important transmission route.[1] Small respiratory droplets may stay in the air longer than large droplets.[6,7]

Masks that limit airborne aerosols have been particularly important throughout the COVID-19 pandemic.[8] High-quality N95 respirators are recommended to protect from virus-loaded aerosols,[8,9] but these masks have proven difficult to find at certain times throughout the pandemic.[10–12] In the place of N95 masks, basic surgical masks have become commonplace around the world,[13] but these masks are relatively poor-fitting, resulting in reduced protection against airborne virus aerosols.[14]

Saudi Arabia has been under a mandatory masking policy for much of the pandemic, one component of a multi-faceted governmental response.[15] In a survey conducted in Saudi Arabia, 74.8% of people surveyed indicated that they wear surgical masks, and 14% of people surveyed indicated wearing a combination of masks (13.7%) or the niqab only (0.3%) as a face covering to satisfy the mandate's requirements.[16] Based on informal observation, it is likely that a significant portion of the 13.7% mixed mask wearers are mixing another type of face mask with the niqab. Furthermore, in the absence of a government mask mandate, it is likely that women who have gone from wearing a niqab to wearing a surgical mask during the COVID-19 pandemic will revert to wearing the looser-fitting niqab.

The niqab is a traditional Islamic face veil that hangs down loosely from below the eyes to several centimeters below the chin. The niqab is not mandated in Saudi Arabia but is commonly worn by Muslim women around the world. The niqab is most commonly worn by female citizens of the Gulf states, particularly Saudi Arabia where it has been called a "cultural norm and social obligation."[17]

The ghutra is a loose garment that male citizens of Saudi Arabia and other Gulf states often wear on their head, secured by a ring called an aqal. A loose end of the ghutra has sometimes been wrapped around the face to function as a face covering during the COVID-19 pandemic. The ghutra as a face covering has high variability of fit between people who might choose to wrap it in different ways around their nose and mouth.

Data on the effectiveness of the niqab and ghutra in reducing expelled droplets is necessary for wearers of the niqab and ghutra to make informed decisions about their protection from airborne viruses and to inform masking policy decisions for COVID-19 and future epidemics or pandemics. Effects of the niqab on ventilatory function have been published,[17] but to the authors' knowledge there are no data on expelled droplets.

Several studies have developed techniques for detecting expelled droplets, a few of which are described here. Verma et al constructed a simplified model of a cough using a manual pump.[6] The experiment tested the effect of facemask material and thread count on the droplet dispersal pattern by generating tracer particles and with detection by a green laser light sheet. They concluded that masks with several layers of the same or different fabrics block more droplets which also travel smaller distances. Konda et al tested the filtration efficiencies of natural and synthetic fabrics for masks.[18] The experiment pushed aerosol particles (10 nm–6 μm) through a fabric sample into a second detection chamber. The report concluded that the filtration efficiencies for fabrics improved when several layers and different fabrics were used. More tightly woven cotton fabrics with higher thread counts—600 threads per inch (TPI)— showed greater efficiencies (65-90%) than those with a lower thread count (5-55%)—80 TPI. Konda et al relied on tools that are expensive and not easily acquired.

Aydin examined 11 common household fabrics by evaluating their efficiency at blocking high-velocity droplets.[19] They used a metered-dose inhaler and filled its nozzle with 100 nm-diameter fluorescent nanoparticles in distilled water to produce droplets with high initial velocity. Then they recorded videos of the ejected droplets using a camera and performed image analysis to determine droplet size and velocity. A petri dish captures the droplets spread from the inhaler nozzle to measure the size differences of incident droplets when using a fabric shield vs. leaving it uncovered. The report concluded that homemade multi-layer coverings can offer effective protection against the droplet transmission and that most fabrics provide >70% reduction of droplets. A study by Fischer et al evaluated the effectiveness of 14 different face masks in reducing respiratory droplet transmission during speech by estimating the total transmitted droplet count.[20] The experimental setup requires a speaker to wear a face mask and speak across a laser light sheet inside a dark enclosure. Droplets in the light sheet scatter light, are recorded with a cell phone camera, and finally counted by a video processing algorithm. Results show the droplet transmission rate over time for each tested mask ranges from below 0.1% (N95 mask) to 110% (fleece mask) compared to the no-mask trials. While proposing a low-cost approach, the setup was, in reality, relatively costly since they used a scientific grade green laser. The Fischer study served as the basis for the study presented in this paper. Broadly, the literature review reveals substantial work in assessing the effectiveness of common fabrics, but there are only limited studies in which the fabrics were being worn by human participants. None of the studies presented a truly low-cost method for quantifying expelled droplets. Additionally, no studies were found that tested face coverings common in many Muslim-majority countries.

Based on the gaps identified above, the goal of this study was to construct a low-cost droplet detection device and assess the efficiency of naturally worn traditional Islamic face coverings. Results of the study will provide individuals who wear the niqab or ghutra and governmental agencies with data as they make decisions regarding masks and mask mandates.

MATERIALS AND METHODS

The physical system consists of two main sub-systems: (1) the optical design and (2) the box and filtration setup (**Figure 1**). The light source is a green laser (520 nm) with an output diameter of 3 mm costing 510 Saudi Riyal (136 USD). The specifications listed an output power of 1000 mW, but the measured output at steady state was 703 mW (no manufacturer listed, only a third party seller on Amazon, amazon.sa). A 223 Saudi Riyal (59 USD) concave-plano cylindrical lens with an anti-reflection coating (ThorLabs, thorlabs.com) expanded the beam into a laser light sheet without focusing the light in a dangerous high-intensity focal plane. A preowned iPhone 12 pro (Apple, apple.com) was selected as the camera for its 1080p resolution at 240 frames per second slow-motion recording at 120° viewing angle. All of the mounting components were custom designed and 3D-printed using polylactic acid (PLA).

The box and filtration setup consisted of a main experiment box painted black to minimize light scattering noise and a subsequent light capture box. The main experiment box had six holes. For the laser light sheet, there was a slit for light sheet entrance (39 cm × 1 cm) into the experiment box and a slit for light sheet exit (52 cm × 1 cm) from the experiment box. Orthogonal to these slits, on the sides of the box, were the circle speaker hole (18 cm diameter) and the circle camera hole (4 cm diameter). The speaker hole is designed to fit the face of a person who will speak directly into the box toward the camera. When droplets are expelled from the speaker, they cross orthogonally through the laser light sheet, scattering light that is detected by the camera. The camera field of view is centered on a 40 cm × 40 cm study area. The top of the box had a hole cut with a HEPA filter in its place, and the bottom of the box had (6) a hole cut with an additional HEPA filter and a high-powered fan. Prior to any trial, air was pushed through the bottom HEPA filter for one minute in a positive-pressure clearing process. This process

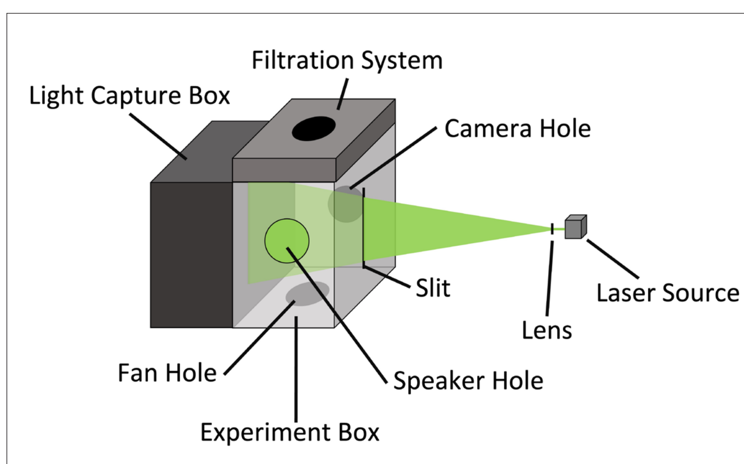

Figure 1. Device setup includes the green laser light sheet, the main experiment box with 6 holes and the final light capture box. The main experiment box is 65 cm tall, 50 cm wide (speaker hole to camera hole), and 55 cm deep.

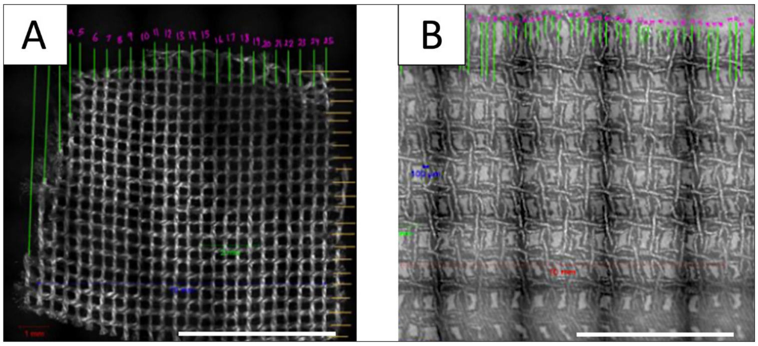

Figure 2. Microscope images of each fabric were used to determine thread count: (A) cotton ghutra, 122 TPI; (B) crepe niqab, 213 TPI (White bars are 5 mm).

Figure 3. An example video frame shows expelled droplets in white/green against a black background.

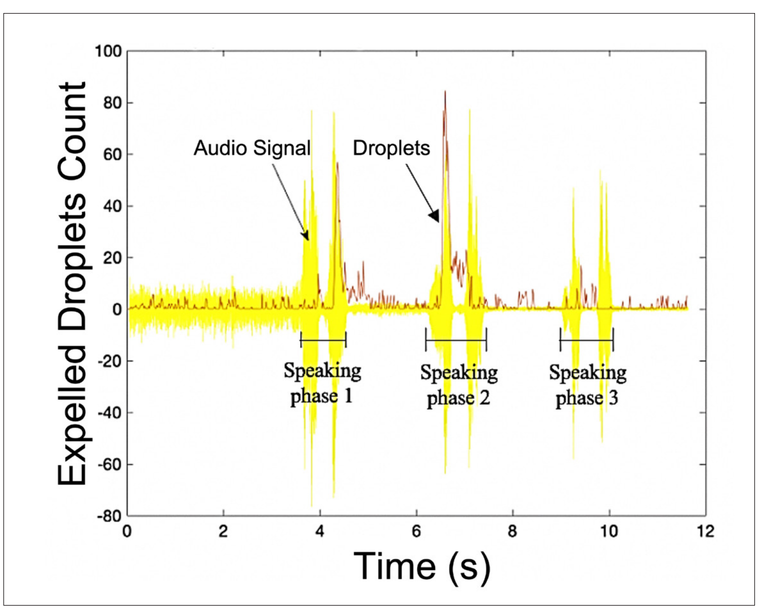

Figure 4. Results from a ghutra trial show the audio signal in yellow and the number of detected expelled droplets in red for three repetitions of the same Arabic word, "setta." The peak value of expelled droplets count is taken as the sample for each of the three speaking phases of the trial.

was demonstrated to remove most noise due to floating dust particles; in a test of the filtration system, fewer than 10 particles were detected for two minutes after the positive-pressure clearing.

The image processing algorithm was implemented in MATLAB (Mathworks, mathworks.com). First, audio was extracted. Next, each frame of the video was sharpened, converted to grayscale and thresholded to binary. Droplets were detected by MATLAB's bwconncomp function which finds connected components in a binary image. The function is set to count 4-connected pixels. The number of expelled droplets can then be determined at every frame of the video, corresponding to the recorded voice of the study participant. The algorithm was validated by comparing its results with the results of the similar Fischer study.[20] Using the Fischer video data, our algorithm detected the number of particles within 2.1% of their reported findings, a reasonable replicated outcome.

In this study, three different participants spoke in the speaker's hole of the device saying the Arabic word for six, "setta," for two different face coverings, a negative control, and a positive control: cotton ghutra, 122 TPI; crepe niqab, 213 TPI; no face covering, and a standard three-layer surgical mask. The word "setta" was selected because it is a short word, ideal for isolating impulse-like droplet events for less convoluted analysis, and because it contains both a fricative (s) and plosive (t) sound, the most likely sounds in human speech. **Figure 2** includes images from a microscope used to determine thread count. In an example image, droplets can be seen as white/green dots on a black background (**Figure 3**). An example recording is shown in **Figure 4**.

For each trial, the speaker said "setta" three times as the camera recorded the study area. Between each recording the filtration system was turned on for 90 seconds and the speaker's hole disinfected. The peak droplet count for each utterance of "setta" was considered as one sample. To analyze the data using parametric methods, we first confirmed that the data were normally distributed. The Kolmogorov-Smirnov test was performed to determine if the peak droplet counts were each normally distributed within a face covering group. The null hypothesis for the K-S test is that the data came from a standard normal distribution with the mean and standard deviation equal to that of each group (α=0.05). If the null-hypothesis was rejected (indicating non-normality), the non-parametric Wilcoxon rank sum test was performed on each two-group combination of the samples. The null hypothesis for the Wilcoxon rank sum test was that data from continuous distributions had equal medians.

Finally, to extract more intuitive information, the relative droplet count between each face covering and the 'no mask' trial was calculated by determining the mean percent reduction in detected expelled droplets:

$$percent\ reduction = 100\% - \frac{D}{D_0},$$

where D is the mean maximum number of droplets detected for any face covering group, and D_0 is the mean maximum number of droplets detected in the no face covering control. The percent reduction calculation was performed for each participant, each trial, and each mask. The average and standard deviation were then calculated across all trials for each participant and mask.

RESULTS

The image frames were successfully processed to obtain maximum droplet counts per utterance to be statistically analyzed. The results of the K-S test gave a *P* value <.05 for all groups, rejecting the null hypothesis, indicating that groups were not normally distributed. Subsequently, the Wilcoxon rank sum test was performed on each combination of groups. The Wilcoxon rank sum test showed a significant difference between all face coverings (**Table 1**).

Subsequently, the results of ANOVA gave a *P* value <.05, rejecting the null hypothesis and indicating that there is at least one significant difference between the mean of the sample groups. The *t* test showed percent reduction of detected droplets for each participant compared with no mask was greater for the surgical mask than the ghutra and niqab. The mean (standard deviation) percent reduction for each mask type compared to the no mask trial was: 76% (24%) for the cotton ghutra, 93% (2%) for the niqab, and 95% (1%) for the surgical mask. The maximum droplet counts detected were substantially lower for surgical masks compared with the ghutra (**Figure 5**). The highest counts occurred with no mask.

Table 1. Comparison of mask types by maximum droplet counts.

	Maximum droplet counts
Ghutra	14.5 (3.6-131.0)
Niqab	7.2 (2.3-11.1)
Surgical mask	5.0 (2.14-8.2)
No mask	54 (5.8-656)

Data are median (minimum-maximum). *P*<.01 vs each comparison (Wilcoxon rank sum test).

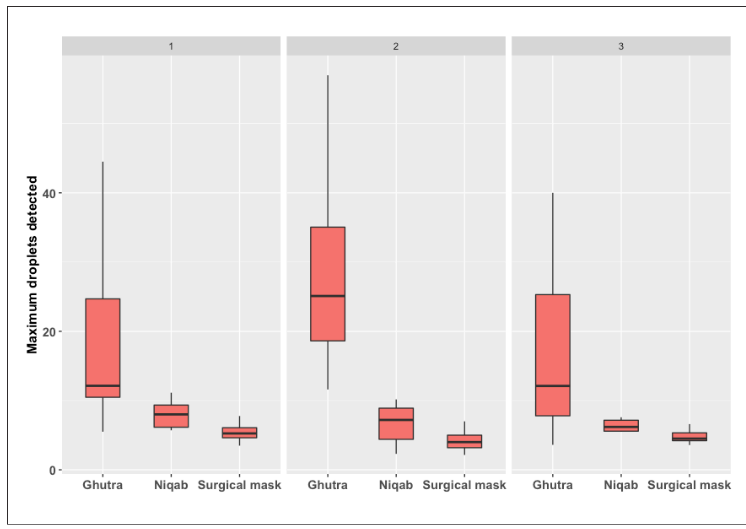

Figure 5. Maximum droplet counts for three masks for each participant (median, IQR, 1.5xIQR; outliers not shown).

DISCUSSION

This study demonstrated a 95% average reduction of expelled droplets using the surgical mask, whereas other studies showed a 99.7%,[19] 99% reduction for a single speaker,[20] and a 94% reduction for the average of four speakers.[20] Thus, this study's results for the surgical mask are generally aligned with other reported data, corroborating the reliability of the setup.

The effect of the niqab and ghutra in limiting expelled droplets seems to depend on thread count and fabric type; indeed, various studies have indicated that higher TPI fabrics have a greater percent reduction of particles.[21] Where another study measured the reduction of expelled droplets with a single layer 150 TPI cotton mask to be 72%; this study measured a similar 72% average reduction of expelled particles for the 122 TPI cotton ghutra. However, this study makes an important extension to the assessment of droplet reduction from fabrics with similar thread counts because it examines uniquely-fitting traditional Islamic face coverings worn during speech. The similarity in droplet reduction between facemasks with similar thread counts but different constructions and fit could not be assumed.

Comparing the data for the surgical masks and the single-layer cotton masks corroborates what has been previously reported in the literature regarding the mean droplet count reduction, but the variability of the reduction was greater. Notably, the standard deviation of the ghutra as a face covering was relatively high, indicating increased variability between samples within a group compared the other studies and compared to other face coverings in this study. The variability is likely due to non-uniform fit. In the experiment, the ghutra was repeatedly wrapped around the face as a man might wear it; this naturally would result in some variability between samples and participants.

Again, while the fabric types used in constructing ghutras and niqabs have been tested elsewhere, the actual construction and fit of the niqab and ghutra is relevant. A niqab, for example, is not worn like a typical facemask, but hangs down loosely in front of the face. The high variability in droplet counts may suggest that effectiveness of a traditional Islamic face covering is highly dependent on its fit. While this study quantifies droplet expulsion, additional study is needed on the direction of expelled particles given the unique nature of how the niqab and ghutra are worn as well as the effect of different expulsion forces during coughing or sneezing.

This study and its implications are limited by two main factors. First, due to the setup of the optical system, the detectable droplets are only those droplets scattered from the speaker in the forward direction. Other droplets may be expelled by the speaker that are not visible in the light sheet. Nevertheless, the study offers valuable relative reduction rates related to mask type. Additionally, the optical system is only able to detect particles greater than 5 μm in diameter. The effect of mask type on particles less than 5 μm is thus unexamined, as is the effect of mask type on the distribution of particle sizes.

In conclusion, using a low-cost device similar to that desribed by Fisher et al[20] for quantifying expelled droplets, we measured the expelled droplet counts and calculated percent reductions in expelled droplets for traditional and Islamic face coverings commonly worn in the Arab Peninsula—the ghutra and the niqab. This study shows that niqabs do not limit droplet expulsion as much as surgical masks but do offer a significant reduction of expelled droplets. A ghutra offers less reduction than surgical masks or niqabs, but also reduces the number of expelled droplets significantly. Both the niqab and ghutra have increased variability in the reduction of expelled droplets when compared to surgical masks.

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