Steimle et al. International Journal of Emergency Medicine (2025) 18:94
https://doi.org/10.1186/s12245-025-00892-6

International Journal of Emergency Medicine

RESEARCH

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A pilot study of coughing into the shirt to disrupt respiratory pathogen transmission

Matthew D. Steimle[1], Jacob Steenblik[2*], Brandon D. King[3], Amy A. Gooch[4], Jeremy Baird[3], Jane Yee[3], Valerio Pascucci[5], Margaret Carlson[6] and Patrick Ockerse[3]

Abstract

Background Scientific evidence is lacking for the respiratory etiquette maneuver of coughing into the elbow. This pilot study introduces and evaluates a novel maneuver " coughing into the shirt" comparing effectiveness of containing respiratory plumes to existing respiratory etiquette strategies.

Methods In this open-bench, observational respiratory etiquette pilot study, five healthcare workers performed four respiratory etiquette maneuvers including: unobstructed, into the elbow, into a mask, and into the shirt. Observational data for the cough maximal plume area, an area calculation, were collected using slow-motion video recording. The various respiratory plume areas of the participants were compared to the unobstructed maneuver, assessing the percent reduction of the maximal plume area.

Results All respiratory etiquette maneuvers significantly reduced the maximal plume area as compared to the unobstructed condition ($F(3,12) = 18.56$, $P < 0.005$). Comparing the maximal plume area of the unobstructed maneuver to the "into the shirt" maneuver, we found a 95.4% decrease for the "into the shirt" respiratory etiquette maneuver ($P < 0.005$). There was no statistically significant difference when comparing the obstructive maneuvers to each other. Additionally, the maximal plume area from the "into the shirt" maneuver was 35.75% less than the "into the elbow" maneuver ($P = 0.15$). Comparing the maximal plume area of the "into the shirt" maneuver to the "into the mask" maneuver, results were inconclusive, with an average difference of 2.24% ($P = 0.66$).

Conclusions Coughing into the shirt may offer superior containment of the respiratory plume than coughing into the elbow. Larger studies are warranted to validate these findings and guide future public health recommendations.

Study design Open bench, observational, cough etiquette pilot study comparing the into the shirt respiratory etiquette maneuver to other respiratory etiquette maneuvers.

*Correspondence:
Jacob Steenblik
Jacob.steenblik@hsc.utah.edu
[1]Departments of Pediatrics, Division of Pediatric Emergency Medicine, University of Utah, Salt Lake City, UT, United States of America
[2]University of Utah College of Nursing, Salt Lake City, UT, United States of America
[3]Department of Emergency Medicine, University of Utah School of Medicine, Salt Lake City, UT, United States of America
[4]Scientific Computing and Imaging Institute, University of Utah, Salt Lake City, UT, United States of America
[5]Visus LLC, Salt Lake City, UT, United States of America
[6]Department of Surgery, University of Utah School of Medicine, Salt Lake City, UT, United States of America

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Background

Infectious respiratory diseases (IRD's) are a leading cause of morbidity and mortality throughout the world [1]. Lower respiratory tract infections are the fourth leading cause of death, causing three million deaths in 2016, killing more people than human immunodeficiency virus, tuberculosis, and malaria combined [2, 3]. IRD is the leading cause of death for children under five years of age [4]. Additionally, these numbers do not include the annual 250,000 to 650,000 deaths caused by influenza, or the 1.5 million deaths from tuberculosis [5, 6].

Several studies have shown that coughing and sneezing have both an airborne and droplet component, contained within a multiphase cloud or plume, and may travel more than six feet [7, 8, 9]. It is unclear what portion of IRD's are transmitted via the airborne or droplet route, as well as what portion is transmitted via coughs and sneezes versus tidal respiration. Respiratory etiquette is our first line defense against IRDs and is employed at the genesis of the chain of transmission during a cough or sneeze, as the contagion exits the host's mouth or nose.

The handkerchief and its international predecessors have served a utilitarian and hygienic purpose for over three thousand years [10]. With the discovery and acceptance of the germ theory [11] of disease in the late nineteenth century, the handkerchief maintained its role as the primary respiratory etiquette (RE) tool, but with a better understanding that coughs and sneezes transmit IRD. The phrase, "coughs and sneezes spread diseases", originated in the 1918 influenza pandemic to support the United States Public Health Service Campaign [12]. During World War II, the British Ministry of Health made full use of the phrase in a successive poster campaign that instructed the reader to "trap the germs in your handkerchief to help keep the nation fighting fit" [13].

The first mass-produced facial tissues were introduced in 1924 and were initially marketed as a cold cream remover; however, they were more often used as disposable handkerchiefs by consumers [14]. In 1930, advertising was changed to reflect this usage with the slogan, "don't put a cold in your pocket!" [15]In the late 1940's scientists confirmed that handkerchiefs and hands play a role in the transmission of IRD as fomites, resulting in the further decline of cloths being used as a tool for RE [16]. In 2006, an otolaryngologist introduced the into the elbow maneuver with the video's release "Why Don't We Do It in Our Sleeves" [17]. The into the elbow maneuver rapidly gained acceptance with individuals and public health organizations despite the lack of scientific evidence to support its efficacy. In 2010, the *MythBusters* TV show performed "The Safe Sneeze Experiment" highlighting the ineffectiveness of current RE manuevers [18]. Various papers were introduced between 2013–2020, further highlighting the lack of scientific evidence supporting the current RE maneuvers [2]. More recent studies have shown the efficacy of using masks as a form of respiratory source control [19, 20].

With the recent global pandemic caused by SARS CoV-2, multiple studies have highlighted how the novel Coronavirus infection is spread and transmitted [21–29]. Since there is evidence of numerous transmission modes, it is essential to perform the best respiratory etiquette maneuvers guided by up-to-date evidence. Some of the current respiratory etiquette maneuvers lack evidence and should be scrutinized. The demand for public health measures requires research into a more effective etiquette maneuver now more than ever. With this premise, we draw attention to the existing literature on respiratory etiquette and introduce a new intuitive respiratory etiquette maneuver namely into the shirt. This pilot study was intended to test the feasibility of methods and procedures and obtain preliminary data to guide further evaluation to search for possible effects and associations.

Methods

Study design and oversight

The main objective of our study is to determine if this novel respiratory etiquette technique, into the shirt, is feasible to perform, study, and analyze using available standard technology to make preliminary observations. Our investigator-driven, single-center study was approved by the University of Utah Institutional Review Board (the protocol is available with the full text of this article at http://www.biomedcentral.com, Appendix. S1 in the Supplementary Appendix). We provide an open-bench, observational, respiratory etiquette pilot study conducted as a small observational experiment with healthcare workers as the volunteer participants. A group email was sent to all emergency department staff in the two weeks prior to the experiment, requesting volunteers. It included an explanation of the experiment and had a consent cover letter (Fig. S1 in the Supplementary Appendix). All participants provided informed consent.

Eligible participants were screened for the following infectious respiratory disease symptoms: cough, body aches, chills, fever, and loss of taste or smell. Additionally, temperatures were taken on all participants. No participants were excluded due to IRD symptoms.

The study was conceived and conducted by the investigators at the University of Utah, who collected and analyzed the data. All authors had access to the data and vouch for the accuracy and fidelity of this report (available at http://www.biomedcentral.com). All research was performed in accordance with the Declaration of Helsinki.

Participants
The healthcare worker participants were selected via response to an email, based on availability and willingness to participate at the experiment time. All participants worked primarily in the emergency department at the University of Utah Medical Center. Three of the participants were female and 2 were male. They all had different backgrounds, including four registered nurses, one emergency medical technician, and one pharmacist. One nurse was excluded for the inability to produce a robust voluntary cough or measurable plume. Data from these five participants were analyzed to conclude feasibility and obtain preliminary observations.

Study site
The experiment was conducted in an outside unoccupied negative pressure overflow tent intended for respiratory patients with possible SARS-Cov-2 symptoms.

Procedures
Appointments were made with volunteers for scheduled times, allowing participants to be screened with exclusion criteria as per prior, reread the consent letter, answer any questions, and provide written informed consent. After completing the prescreening, participants were asked to change into a black long sleeve shirt and proceed to the coughing station. The coughing station was set up using a black photographer's curtain as a backdrop, illuminated by two umbrella studio lights. Markings were made at 12-inch increments along the top of the black photographers' curtain backdrop extending to 120 inches. Participants were asked to stand at a dedicated location and read the coughing instructions (Fig. S2 in the supplementary appendix). The participants were asked to produce four coughs: unobstructed, into the elbow, into the mask, and into the shirt. To simulate a cough plume or cloud, (hereafter referred to as a cough plume, respiratory plume or plume), the experiment used powdered sugar to simulate a cough plume with droplets. The participants were asked to: take a deep breath to fully inflate their lungs, empty the powdered sugar from the dosing cup into their mouths, then elicit their best effort coughs using the above respiratory etiquette maneuvers in an open bench format. The cough plume was recorded using a Samsung Note 10 + 5G phone on a tripod was used to capture each cough in slow motion mode (240 frames per second at a resolution of 1920 × 1080 pixels). Multiple video clips were made for each participant (Links S1-S4 in the Supplementary Appendix). All five participants completed the 4 different cough maneuvers and were given adequate time in-between coughs recover for the next sequence.

Data processing
Following video capture, we analyze each cough recording to find the cough maximal plume area (MPA). Although we did not encounter this term or abbreviation in the existing RE literature, we will hereafter refer to this area measurement as cough MPA for ease of description. (Details of our software process are illustrated in Fig. S3 in the Supplementary Appendix). Our data processing software is written in Python using OpenCV and Numpy libraries. Our software processes slow-motion videos to find an approximate area occupied by the white plume. The white tape on the background and pixels occupied by the participant prohibits the image's simple thresholding from finding which frame of the video has the cough MPA. We found the easiest way to limit the number of pixels occupied by the participant, and the tape is to create a "tape mask", which in image processing means to replace the regions with gray values below the threshold used to find cough particles.

The algorithm first creates the tape mask by taking the video's 0th frame and marking the tape lines via thresholding in hue saturation value color space. We use the 0th frame because the plume we are looking for is white, and the 0th frame does not yet contain any plume pixels. We mark these regions with a dark color that is below our thresholding value.

We sequentially analyze every frame, in search of the highest number of cough (white) pixels. For each frame N, we remove "skin" pixels by thresholding in hue saturation value (HSV) color space. We choose to automatically remove tape and skin as much as possible to find a more accurate account of which frame in a participant's sequence had the largest number of white pixels.

The HSV threshold values are as follows:

[0, 0, 180] ≤ tape threshold ≤ [255, 38, 255].
[0, 0, S] ≤ skin threshold ≤ [40, 90, 255], for S in [210,240].

Once we minimized the number of the skin or background pixels, we applied Contrast Limited Adaptive Histogram Equalization [30] (with a clip Limit = 3.0, tile Grid Size = (8, 8)) on the luminance channel in LAB color space to brighten the image. We found this to be an essential step in separating the plume from the background. Next, we threshold the contrast adjusted image, empirically finding that a plume threshold of 99 in [0, 255] worked for the images in our dataset. We recorded the frame number and number of white pixels for this frame and repeated the other frames' processing.

Once the frame with the largest number of white pixels was found, we cleaned up the thresholded image to get a more accurate count of the plume's size. Next, the contour finding algorithm was used to group nearby white pixels accurately. We then used a distance threshold to combine the grouped pixels and calculate the maximal plume that enclosed the contours, calling this cough maximal plume area (MPA). The results for participant 4 are shown (Fig. 1). Results for all participants across all maneuvers are provided (Figs. 2 and 3, Table 1).

Statistical analysis

Descriptive statistics were used to compare the cough MPA between each RE maneuver. The cough MPA was normalized to the unobstructed maneuver across each subject rather than raw pixels to account for individual differences in the baseline force used to generate a cough. This also adjusted for the distance away from the camera that varied slightly between subjects. A repeated-measure ANOVA testing was used to assess for statistically significant differences between the normalized cough MPA across RE maneuvers. We use paired t-testing to compare the mean differences between two groups. Each RE maneuver was considered an independent variable. A p-value cut off of 0.05 was used to determine statistical significance. Analysis was done on STATA/IC 16.1 software.

Results

We enrolled five volunteers subjected to 4 RE maneuvers. Compared to the unobstructed maneuver, we found an overall decline in the cough maximal plume area (MPA) when any obstructive maneuver was performed (Fig. 3, Table 1).

We normalized pixel differences across each participant, comparing the percentage of cough MPA for the unobstructed to all other maneuvers. Different RE cough maneuvers elicited statistically significant differences in cough MPA ($F(3,12) = 18.56$, $P < 0.005$. Specifically, when compared to the unobstructed maneuver, we found an overall statistically significant decline in the cough MPA when any obstructive maneuver is used. Comparing the cough MPA of the unobstructed maneuver to the other RE maneuvers, we found a 59.6% decrease for into the elbow RE maneuver ($p = 0.04$), a 93.2% decrease for into the mask RE maneuver ($p < 0.005$), and a 95.4% decrease for into the shirt RE maneuver ($p < 0.005$). There was no

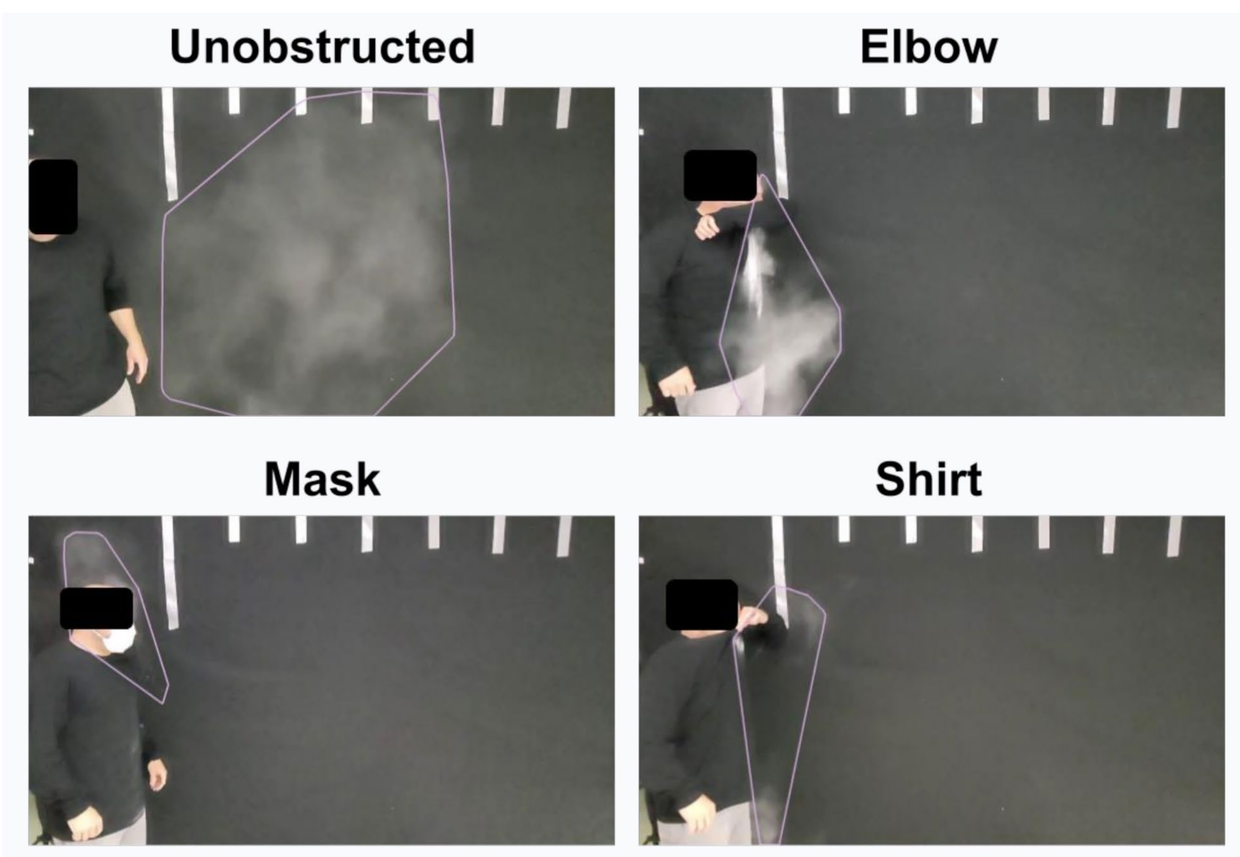

Fig. 1 Cough maximal plume areas of the four respiratory etiquette maneuvers. Summary of cough maximal plume area (MPA) for anonymized participant 4 across all four respiratory etiquette maneuvers from the slow-motion videos. Each still image is annotated with the software detected maximal plume pixel boundary (pink outline). The unobstructed cough maximal plume area (MPA) is much bigger in area than the other maneuvers. The elbow maneuver produces a dense cloud of dust, whereas the mask and shirt maneuvers reduce the number of released particulates

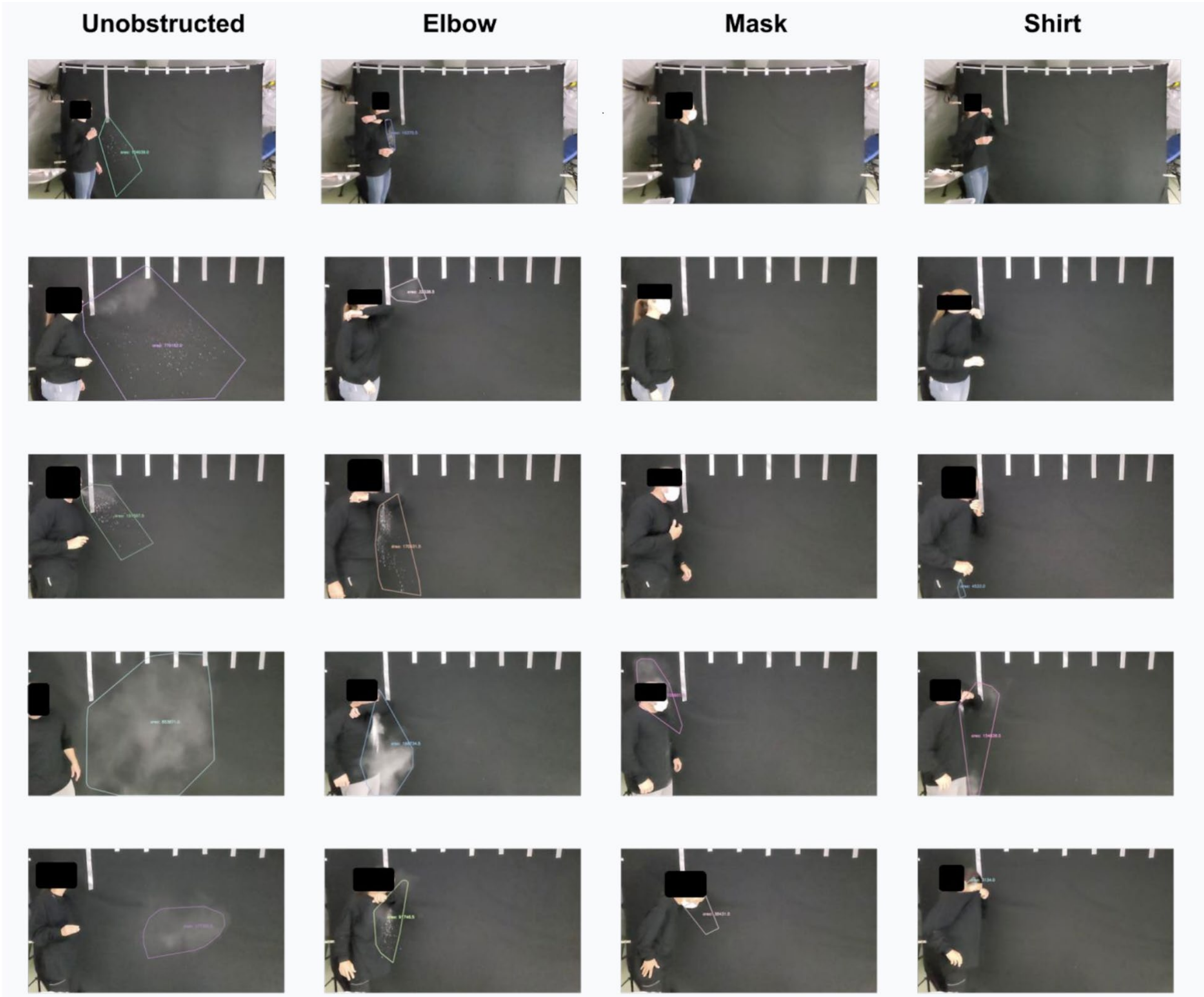

Fig. 2 Summary cough maximal plume areas (MPA) for all participants and respiratory etiquette maneuvers, Summary of cough maximal plume area across anonymized participants from the slow-motion videos. Each video still image is annotated with the software-detected cough maximal plume area (MPA) across all four maneuvers. Some participant's maneuvers did not result in software-detectable plumes notably in the into the shirt and mask maneuvers.

statistically significant difference when comparing the obstructive maneuvers to each other. Additionally, the cough MPA from into the mask maneuver is 33.52% less than the into the elbow maneuver ($p = 0.17$), and the cough MPA from into the shirt maneuver is 35.75% less than into the elbow RE maneuver ($p = 0.15$). Comparing the cough MPA of the into the shirt maneuver to the into the mask maneuver overall participants were inconclusive with an average difference of 2.24% ($p = 0.66$).

Discussion

With a stationary camera, it is possible to compare within-subject pixel counts, but such a method is limited in precision by the participant's distance from the camera and problems with false positives due to the highlights from the participant or backdrop and particles in the air. It is also difficult to differentiate plumes that overlap with a backdrop and tape markings and plumes overlapping with clothing and skin. Sometimes the software couldn't differentiate the plume, such as when the into the shirt cough plume accumulates against the participant's pants or against their facial skin.

Future experimental setup should consider dressing participants in all black (black pants, black gloves, black cap, black mask) and choosing a very matte material for the clothing. The background should also be uniform, non-specular, and perhaps distant from the cough so as to not build up a residue of sugar. The tape was useful for understanding how far the plume extended. Still, the tape should preferably be a unique color such as a dark red or green, which would be easy to differentiate from the plume and easy to extract with image processing. As in this experiment, the camera should be placed in the same position for all data capture, with high contrast lighting.

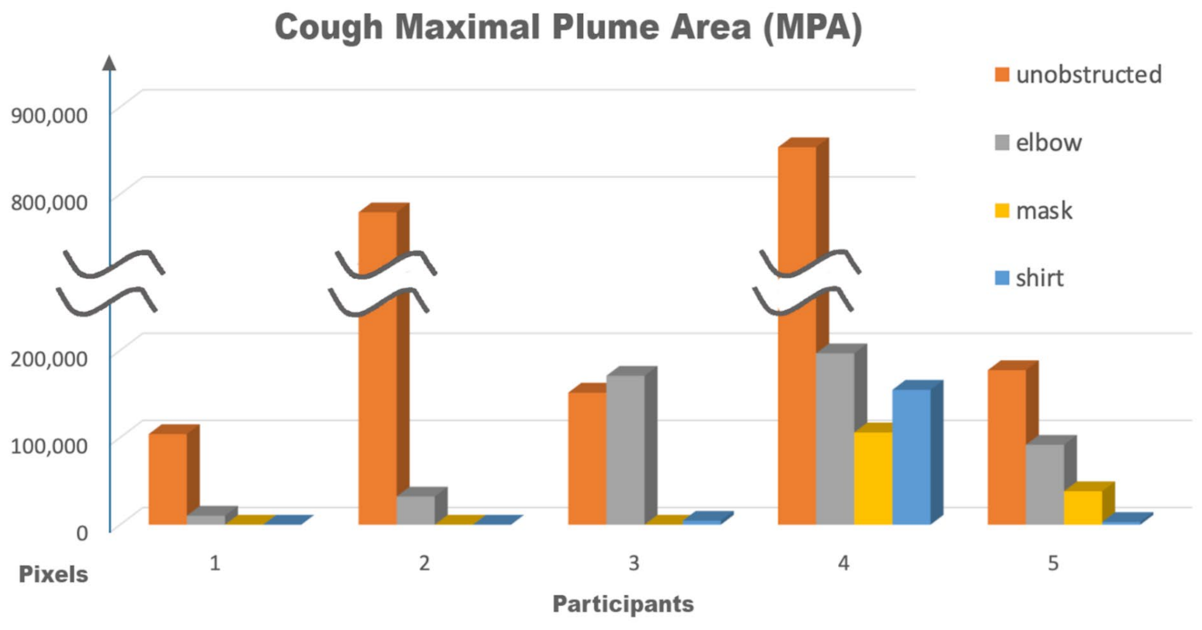

Fig. 3 Cough maximal plume area (MPA) pixel counts across all participants (1 through 5) and all maneuvers: unobstructed, elbow, mask, and shirt. The shirt maneuver generally shows cough MPA on par with the mask maneuver, except for Participant 4, which shows many white pixels that escape an untucked shirt or placement of the mouth relative to the shirt collar

Table 1 Cough maximal plume area (MPA) in pixels by participant and maneuver

Participant	Unobstructed (Pixels)	Elbow (Pixels)	Mask (Pixels)	Shirt (Pixels)
1	104,039	10,371	0	0
2	779,152	32,339	0	0
3	151,588	170,932	0	4,533
4	853,871	196,735	105,901	154,837
5	177,353	91,747	38,432	3,134

Obtaining an image of the background without any participant is preferable as it would allow for background subtraction. This study focused on a two-dimensional area measurement cough MPA, future studies may want to target three-dimensional volume measurements of plume size, by incorporating a camera angle from above.

The current Centers for Disease Control and Prevention (CDC) recommendations for RE include coughing or sneezing into a tissue as the primary mechanism of containing the respiratory plume, then disposing of the tissue and hand cleaning. The into the tissue maneuver is not addressed in this study and it may be worth investigating this maneuver in comparison to the other RE maneuvers. However, we question the practical application of this maneuver based on the general availability of tissues, wastebaskets, and hand sanitization. As a secondary recommendation, the CDC states, “If you don’t have a tissue, cough or sneeze into your elbow, not your hands.”

A review of current literature supporting the into the elbow maneuver revealed no recent, validated or scientific data to support the recommendation. We doubt that the technique is effective at containing the respiratory plume generated by coughing or sneezing. This experiment supports the use of RE maneuvers in reducing droplet and likely aerosol dispersion from coughing in comparison to unobstructed coughing. The findings also show that coughing into the elbow had the least containment and suggest it is less effective compared to coughing into the mask or shirt. The study did not find a statistical significance between each of the RE maneuvers however due to the small sample size. It is also not powered to test non-inferiority, superiority, or equivalence between the maneuvers. Analysis of images previously described demonstrate that the into the elbow maneuver did little to decrease the size of the respiratory plume, compared to into the mask or into the shirt maneuvers. There was some redirection of the plume, but the overall direction of force remained in the forward direction. The into the shirt maneuver, however, revealed more plume containment, any remaining plume was directed downward.

This was a small proof of concept study intended to bring awareness to respiratory etiquette maneuvers. The current study has shown the advantage of this novel into the shirt maneuver. A cross over design and large-scale investigation with advanced technology is warranted.

Although not the primary focus or intent of our study, we additionally observed that the into the mask maneuver contained the respiratory plume well, thereby providing additional data advocating for the use of masks.

Some participant maneuvers did not result in software-detectable plumes notably in the into the shirt and mask maneuvers. The maximal distance that was recorded was nearly the same for the elbow and shirt maneuver at 12 inches however, the MPA for the elbow was much greater and not reportable on the shirt maneuver. We also found that some unobstructed cough plumes and droplets dispersed beyond 6 feet, further questioning current recommendations of maintaining 6-feet physical distancing.

Limitations

As this study was intended as a pilot project, there are limitations that should be noted. This study included a very limited number of participants. Future studies should expand and include a larger data set. Future studies should also look at the order and cough sequence which the participants performed the cough. Patients for this pilot project were not randomized to a cough sequence. Additionally, other demographic information should be collected including body mass index, smoking status, age, lung capacity, etc.

The powdered sugar was used to create a measurable plume, but whether it accurately represents respiratory droplets and aerosolization of pathogens associated with IRDs is unknown. As the into the shirt maneuver was novel for most, we observed some variability in how volunteers performed the maneuver. Additionally, whether the shirt is tucked in, the type of material the shirt is made from, and the accessibility of coughing into the shirt are all variables that influence the effectiveness of the maneuver.

Conclusions

The assessments gleaned from this observational study highlight the feasibility of both the pilot study and this innovative respiratory etiquette maneuver and strongly supports additional study with appropriate power and sample size calculations in dedicated laboratories. With further evaluation the into the shirt RE maneuver may prove to be superior to the into the elbow RE maneuver, for containment and practicality. Insisting upon evidence-based respiratory etiquette research is essential to decrease global morbidity and mortality from infectious respiratory diseases.

The authors would like to thank Shawn Steidinger, MLS, AHIP, for technical assistance accessing, searching, and cataloging references from digital libraries.

Abbreviations

CDC	Centers for disease control and prevention
HSV	Hue saturation value
IRD's	Infectious respiratory diseases
MPA	Maximal plume area
RE	Respiratory etiquette

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12245-025-00892-6.

Supplementary Material 1

Acknowledgements

We thank Shawn Steidinger, MLS, AHIP, for technical assistance accessing, searching, and cataloging references from digital libraries.

Author contributions

MS, JB, VP, PO, JS, AG - Wrote the main manuscriptJY, MC, PO MS BD, - Contributed to study design All authors reviewed the manuscript.

Funding

No extramural funding was provided for this study. This study was internally funded from the Department of Emergency Medicine at the University of Utah.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Human Ethics and Consent to Participate declarations: This study was covered under the University of Utah, Assessment of Emergency Medicine Training Techniques for ED Personnel Exemption Umbrella. All participants signed an informed consent form prior to participating. IRB #00080204.

Consent for publication

All the authors meet the following criteria for authorship: Drafting the work or revising it critically for important intellectual content; and Final approval of the version submitted for publication; and Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved

Competing interests

The authors declare no competing interests.

Received: 18 February 2025 / Accepted: 26 April 2025
Published online: 08 May 2025

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