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Designing Affordable and Effective Easy-to-Make Personal Protective Equipment (PPE) During Global Healthcare Crisis: Lessons Learned during COVID-19 Pandemic

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Abstract: This study was conducted at the onset of the current pandemic. During initial few months of its start, the fear of severe acute respiratory syndrome coronavirus 2 (COVID-19) in the United States resulted in acute shortage of personal protective equipment (PPE) for first responders and healthcare providers. At the start of the pandemic, manufacturers could not keep up with competing public demand as well as healthcare facilities' needs. Therefore, alternative PPE-like equipment that was affordable and readily available were needed. Since it was thought that the main mode of transmission of COVID-19 was nasopharyngeal droplet and face tough, in theory any devices that could reduce those two factors, would reduce the risk of transmission. In the current study, the authors used common household items to design face shield with three objectives. Firstly, design effective cheap aesthetically appealing PPE to reasonably protect the persons and reduce the competition against healthcare systems. Secondly to evolve school aged children in scientific exploration while schools were dismissed due to the pandemic indefinitely. Lastly, inspire methodologies that could be helpful in future global crises of sudden onset. We hypothesized that the face shield in this study would reduce both spreading of nasopharyngeal droplets and face touch. With the caveat of having limited resources, face shields were effective in blocking macroscopic fluorescent droplet (100%) from reaching a face. It also contained (100%) of macroscopic fluorescent droplets within the shield when a person wearing the shield coughed. The face shields also significantly reduced the amount of time in seconds individuals touched their faces (n=6, *p*=0.01). The youth in the study demonstrated compassion, dedication, and contributed significantly to the final product that was well received by healthcare providers. We demonstrated that in a short span of time, with limited resources, one could create effective healthcare tools.

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I. INTRODUCTION

At the time of writing this manuscript (May 4, 2020), according to World Health Organization, the pandemic of severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2) had affected 3,489,053 individuals in 215 Countries, areas or territories, with 241,559 confirmed deaths [1]. As of May 4, 2020, the United States alone reported 1,152,372 cases of SARS-CoV-2 (commonly referred to as COVID-19) with 67,456 deaths [2]. During May of 2020, the Center for Disease Control (CDC) forecasted more cases and more unfortunate deaths [3]. Naturally, healthcare providers are the front-line personnel, rendering them more vulnerable than the general public. Wang et al. reported that, of 138 COVID-19 patients, over 41% were infected in the hospital, most of them (29%) providers (17% other patients). In their study, one person infected 10 healthcare providers [4]. Although far from perfect along with less than optimal compliance [5], Personal Protective Equipment (PPE) could reduce the risk to healthcare providers both in hospital settings as well as community settings. However, there were an acute shortage of supplies around the world including the United States [6]. Weary of the deadliness of the virus, the general public in the United States had rushed to the stores to secure supplies of masks and other types of protective equipment prompting major newspapers and officials to ask the general public not to compete with healthcare providers [7]. On April 20th, Times [8] reported a survey of 978 organizations with 36% having no face shield left in storage. As healthcare providers in the United States, the clinician in this study were personally aware that hospitals were frequently forced to ration simple protective equipment such as surgical masks. More sophisticated equipment (e.g. N-95 masks) were far more difficult, if not impossible, to obtain. Thus, there was an acute need for innovative means to provide the general public with a measure of reasonable protection easing the stress on the supply of medical devices to the medical community. The authors believed that the methods should be easy to follow, be affordable, scalable, aesthetically pleasing, and provide comfortable assurance to the public of their benefit. In an attempt to achieve this, in the current study, we designed and tested Personal Protective Equipment (PPE)-like devices

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made with items accessible to anyone in the United States (as well around the globe). The two most common concerns in regard to the spread of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) were cough droplets and touching one's own face (6). We hypothesized that our design would effectively eliminate direct propulsion of large droplets both from the person coughing and to the person exposed to the cough. We also hypothesized these face shields would reduce the amount of time (measured in seconds) one would touch his/her face.

II. MATERIALS AND METHODS

Clear plastic films were obtained from different vendors. Household items purchased from hardware stores as well as general stores were used to design "face shields". A host of various forms of such shields were designed. Although the final project of this study resembles the ubiquitous fiveheads, the authors had created numerous variations of PPE-like devices as more information became available. Independent of any other entity or research, at the time, the authors had arrived at the conclusion that a simple face shield should be sufficient in alleviating anxiety regarding transmission of COVID-19. The final product used in this study was made as follows: First, clear plastic films were cut approximately 30.48 cm (12 inches) by 0.48 cm costing about $1 each shield (figure 1A). A strip of 5.08 cm (2 inches) card stock paper (folded to 2.54 cm) by 30.48cm (12 inches) was cut and used to hold the plastic shield in place using a common stapler. The paper was padded with mattress foam of approximately 2.45 cm (one inch) thickness, 2.45cm width, and 30.48 cm length. Although any type of stock card paper would work, to safe costs, we used a cheap ones, UCreate ™ (PACON Corporation, Appleton, WI 54913-8865). One sheet of paper was enough to make more than a dozen strips bringing the cost to less than four cents. To hold the shield against the forehead, a curling gift ribbon was used attachable in the back with Velcro (five cents per pair, figure 1A). The face shield could curled for easy transport and shipment without affects its effectiveness.

Fig 1(A):: assembled "Face shield". Approximately 12 inches by 12 inches with one-inch-wide headband.

The contents of Play Glow Colored Sticks® (20 cents/sticks) were used as florescent material (ink pad) to measure the amount of droplets on the face shield (Figure 1B) under *light on* and *light off* conditions.

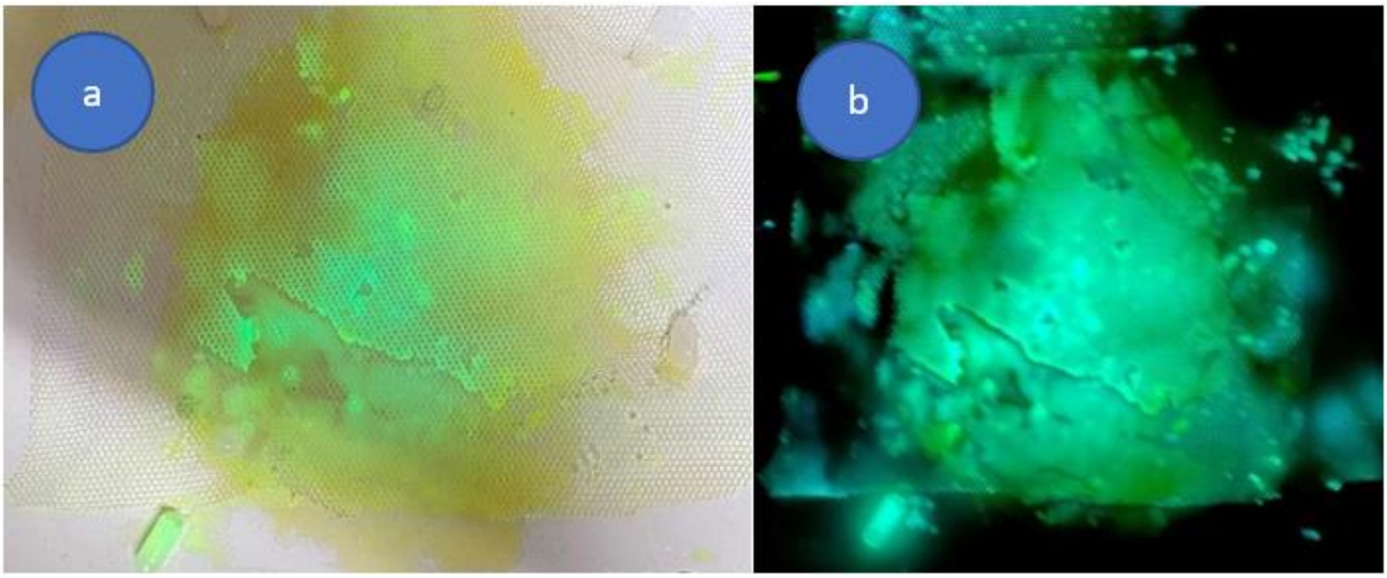

Fig 1(B): Fluorescent Ink Pad with *Light on* (a) and *Light off* (b) Photographed Using iPhone11

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The bottom of a paper cup was cut, and a nylon general purpose screen was attached to the bottom using a hot glue gun (figure 1C), called "coughometer" (to keep the junior researcher entertained). "Coughometer" was used as an estimate of droplets that may be sprayed with each cough. "Coughometer" was filled with an inkpad (figure 1B) between coughs.

Fig 1(C): "Coughometer". Junior researcher posed but never used "Coughometer". The Bottom of the "Coughometer" was Soaked in Inkpad (Figure 1C) and Coughed Thought it to Simulate Propulsion of Macroscopic Oropharyngeal Droplets

In the absence of access to any laboratory and rudimentary materials, a photograph of a junior researcher (figure 2) was taped to a small trash can to mimic human face and head (thus intentionally called "pretend-person" rather than mannequin). A picture of "pretend-person" was taken with lights on and darkness to be later compared to fluorescent droplets spread over the face of "pretend-person" (Figure 2).

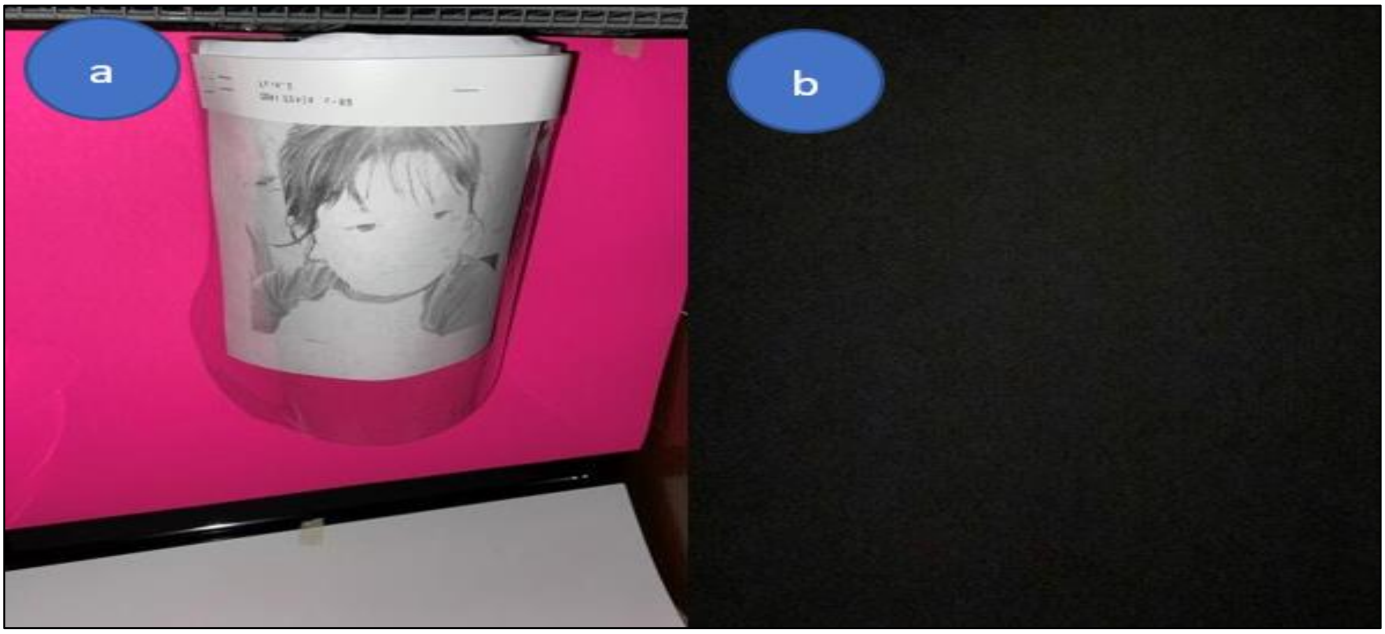

Fig 2: "Pretend-Person" with "Face Shield" Under *Light on* (a) and *Light off* (b) to Compare with Later Experiments

- *Efficacy of "Face Shield" in Preventing Exposure to/Spraying of Macroscopic Droplets*

In summary, in *Experiment 1*, the senior researcher coughed once through the "coughometer" while the "pretend-person" was "wearing" the shield (figure 3). This approach would estimate the amount of macroscopic fluorescent droplets sprayed on the "pretend-person's" face. Experiment 1 was carried out total of 12 times to establish consistency of data collected.

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Fig 3: Macroscopic Droplet of Fluorescent Dye on "Pretend-Person" Exposed to Cough with *Light on* (a) and *Light off* (b) with Shield on and with Shield off. "Face Shield" Seemed to Have Completely Prevented Macroscopic Fluorescent Droplet from Reaching "Pretend Person's" Face (c and d)

In *Experiment 2*, the senior researcher coughed through the "coughometer" holding "Face shield" right in front of "coughometer" (as if a coughing person was wearing the face shield). This approach (figure 4) would estimate the effectiveness of preventing droplets propelled by the person coughing (in this instance, towards "pretend-person"). To compare the results, iPhone 11 was used to photograph "*before*" and "*after*" each cough. Although *Experiment 1* was repeated 12 times, however for safety reasons, *Experiment 2* was conducted once.

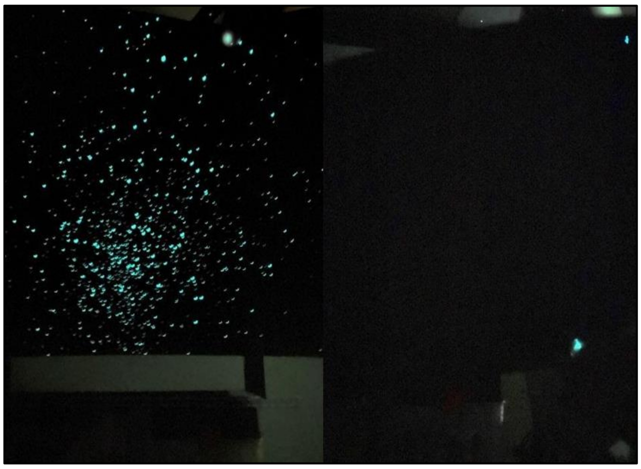

Fig 4: When person coughs while "Face shield" is on; all of the droplets are stopped by the shield (a) and none was sprayed (b) on the "pretend-person's" face. Thus, "Face shield" effectively stops an infected person to spread the virus beyond the shield.

➢ *Efficacy of "Face Shield" in Preventing Face Touch*

Next we measured for how long would a person touch their face without and with the mask. This step of the study was single-blinded, volunteers would have a 20 minute dry run, followed by 30 minutes without "Face shield" shield, and then 30 minutes while putting on the shield. The volunteer did not know what the purpose of the recording was. The senior researchers designed this step of the study, thus did not participate as a subject to reduce bias. Due to social distancing, recruiting subjects was limited to the researchers' household individuals. Informed assent was obtained from junior researchers who were blind to the design of this step. Also informed consent was obtained from adults in the house who were also blinded. Each individual was videotaped using an iPhone 11 camera. After the analysis, for privacy reasons, videos were deleted. The number of times (measured in seconds) each person touched his/her face in 20 min dry run, 30 min control, and 30 min with shield was measured. Paired Student t-test was used for statistical analysis.

- Note: junior researchers never used "coughometer" or sharps, though they did use a hot glue gun, assembled "Face shield".

III. RESULTS

In the 12 try of coughing at "pretend-person" wearing the same "Face shield" washed between each try, there was no recordable macroscopic fluorescent dye on "pretend-person's" face (figure 3), thus, "Face shield" seemed effective at face value. Since the experiments were carried without any sophisticated equipment, we were not able to measure microscopic fluorescent droplets not observable by naked eyes or lens of iPhone11. Since we did not observe any visible ink on the face area of the "pretend-person", we concluded 100% of macroscopic florescent dye was stopped by "Face shield". "Face shield" was also effective in confining "coughing person's" nasopharyngeal droplets within the shield and prevented them from reaching "pretend-person". Since no observable fluorescence was detected on "pretend-person's" face, the outcome was interpreted as 100% confinement of large, macroscopic fluorescent droplets between the coughing person's head and the shield (figure 4). Thus, the first hypothesis of the study was supported by evidence in this small study.

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In regard to face touch, table 1 shows how many seconds each individual touched their face, eyes, nose, forehead, cheek, and chins. Seconds were rounded to one second if touches were shorter in duration. Paired Student t-test (5) was used to compare face touches with "Face shield" on and "Face shield" off. With the shortcoming of the very small number of participant, "Face shield" significantly reduced ($t(5)= 3.95$, $p = 0.01$) the amount of time participants touched their face without "Face shield" (M=103.83 seconds, SD= 60.31) and with "Face shield" (M=4.50 seconds, SD= 4.81). Thus, this observation supported the second hypothesis of the study, "Face shield" seems to reduce face tough by 96%. When comparing dry run and without a shield face touch, there was no difference ($t(5)=0.17$, $p = 0.87$).

Table 1: Shows How Many Seconds a Subject Touched their Face in Dry Run (20 minutes) and Experimental Conditions (30 Minutes Each)

Subject	20 min dry run (Seconds)	30 min without face shield (Seconds)	30 min with face shield (Seconds)
1	217	165	7
2	77	120	1
3	76	32	3
4	145	45	13
5	35	176	3
6	37	85	0

IV. DISCUSSION

Personal Protective Equipment (PPE), if used appropriately, reduces the risk of transmission of airborne infectious diseases to healthcare providers [5]. However, the shortage of PPE in COVID-19 pandemic in the United States had increased the likelihood of healthcare providers and first responders to be less protected [9]. One reason for the shortfall was that the general public obtained such devices in large quantities [7]. Although PPE may be protective in day-to-day use of general public, there may be more affordable and easier to manufacture alternatives that would allow healthcare providers and first responders to have more readily access to acutely needed PPE. In this study, we aimed to show that such general-purpose devices could be designed cheaply and be reasonably effective in both preventing spreading of and exposure to macroscopic oropharyngeal droplets. Furthermore, such devices could be scaled rapidly, be comfortable and fashionable. In this study, the simple face shield was able to stop macroscopic fluorescent dye from spreading. It also reduced significantly the amount of time a person would touch, forehead, cheeks, chin, eyes, nose and mouth (96%, $p = 0.01$). We found this an impressive performance from a device costing under $1.1 (May of 2020). If scaled, the price can be in cents per shield, thus making them cost-effective tools as single-use items both in the community and low exposure-risk hospital personnel (e.g. house cleaning stuff).

There are significant limitations to the study. The laboratory was a "makeshift" home office/basement; materials were commonplace material for daily consumption or children's toys, and the fluorescent droplet size was measured with an unsophisticated device (glow stick contents and iPhone11 camera). Nevertheless, the study achieved its objective of designing a device under severely limiting conditions (during quarantine and school closure) and studying the effectiveness of the device with fairly well-articulated experimental designs. Above all, involving young investigators in all steps of the study, including a then eight-year-old child as a coauthor in a scientific study was a significant achievement from our view point. Each young investigator contributed significantly; for instance, by injecting aesthetic argument in the design, the first author contributed to a 1/4th of the design of a shield (effective, affordable, scalable, and fashionable). Other young authors were able to recruit subjects, obtain informed consent, and analyze the data. It, without a doubt, will enable them to participate in meaningful future scientific research. We showed that our design can be reproduced by anyone with access to basic day-to-day materials and perhaps augmented with others' own creativity. We hoped that this study would invigorate the search for cheap, scalable, effective, and fashionable protective devices for general public and medical communities under severely undesirable conditions. Moreover, we hoped this study would encourage other parents to teach their children the unique skills the parents have when children are not able to go to school. Doing so, without a doubt, did not replace the school dismissal during COVID-19 pandemic, but it did supplement children's educational scope to a degree, even if it is in a specific field more suitable when the children are at more mature cognitive stages. In our study, our junior researchers then understand the importance of designing a "robust" study, using measures of control to ensure the data is collected accurately and biases reduced, statistical analysis to see if the difference is more than random chance, as well as the process of publishing a peer-reviewed article. Here we also showed that parents can use their skills to teach children science and compassion with limited resources. In a practical term, the senior author was the attending psychiatrist at the only COVID-19 positive inpatient psychiatric unit in the District of Columbia. Since there were no PPE at the time, the staff on the unit very much appreciated the free distribution of this face shield before such face shields were available in bulk for healthcare facilities. The face shield that we designed was very well received. One young author, for example, was actively designing "home-made" face shields distributed for free by the senior researcher to his colleagues in the hospital where he worked (a gesture highly appreciated by allied healthcare providers). The most junior researcher not only committed time and efforts but also her own personal funds to support

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the study ("tooth fairy" gifted monies). An additional benefit was that the younger authors were also less anxious about the catastrophic possible outcome in the context of COVID-19 rather were more focused on solution to the problem at hand and ensuring host of issues that were expected in the aftermath of this global disaster with historic proportions.

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