Talking Heads: 3D Head Scanning to Assess the Dynamic Fit of Face Masks

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Introduction: With the ongoing Covid-19 pandemic, various research has been produced regarding different aspects of medical and nonmedical face masks such as design, construction, sizing, material selection, and so forth. Face masks that do not fit well provide poor performance and can cause discomfort (Salehi et al., 2019). Fit is defined by two states: static and dynamic. Much of the static fit research is focused on sizing such as fit maps and test panels (Chen et al., 2015). Static fit is a crucial first-order factor in determining sizing of products interacting with the human body, but it does not necessarily result in constructions that can adapt to the movement of the body during use. Dynamic fit is especially important for cloth face masks as mask shifting during talking can cause performance to diminish, the wearer discomfort, and an increase in the need to touch the mask to reposition it, thus increasing contamination risk. To the best of our knowledge, only one study has attempted to look at the dynamic fit of cloth face masks by scanning a participant with their mouth open (Morishima et al., 2016). While the researchers were able to capture the mouth movements of different vowel sounds and calculate the subsequently required extension percentage, none of the jaw movement tests was done with an actual face mask. Therefore, the present study aimed to develop and apply a method to evaluate new and existing face mask designs considering dynamic fit. Specifically, the initial experiment described in this paper focused on using three commercially available face masks for the methodological development of scanning postures and procedures.

Methods: After receiving an Institutional Review Board approval, two participants were scanned using a Vitus 3D head scanner (Human Solutions) for the experiment. Three mask designs were selected to represent the range of mask designs and sealing capabilities: N95 respirator (3M VFlexTM 1804) with pleats designed to "flex with mouth movement while talking" (3M, n.d.), a typical pleated surgical mask, and a nonmedical cloth face mask with a vertical seam in the front and no added features for extension during talking. Each participant was scanned first without a mask for four scans total, once with his or her mouth closed and once with his or her mouth fully open at both looking straight-ahead and looking up positions. The participant donned the corresponding mask and was allowed to adjust it to a comfortable position they would normally wear the mask (coded here as neutral position). Each mask was scanned in the same positions as "no mask" (Figure 1). While wearing the masks, participants read the Rainbow Passage from the 2004 OSHA quantitative fit test out loud at a normal volume and pace. They were asked to refrain from touching their face or adjusting their mask. The scans were repeated at the completion of the talking exercise. The participants were allowed to adjust their masks back to neutral position before repeating the talking exercise and scanning for a total of three times per mask. All scans were exported in .jpeg format for initial visual comparisons.

Results and Discussion: Two participants were recruited for the initial study, one female (26 years, white, 135 pounds) and one male (23 years, white, 210 pounds).

Both straight-ahead and looking-up postures had incomplete scans of the entire head, but all ears and facial features were unobstructed. Further, no differences were visible between the two head positions in the mask trials, therefore, straight-ahead position was chosen moving forward due to the ability of participants to repeat positions between trials. A reasonable landmark to choose for quantifying mask shift was on the bridge of the nose. All three masks shifted down the nose, so the distance between the initial edge point between the mask and the bridge of the nose and the edge point after talking can be calculated as a single metric to compare the various masks and/or design features. Thus, by coupling the dimensional changes of the face with the dimensional changes of the mask during talking, we can calculate the shifts in the mask relative to the face. Of the three masks tested, the N95 respirator provided the best seal as the pleats accommodated both the female and male faces in closed and open mouth postures, and the headband straps applied enough pressure to maintain mask position. Only during the talking exercise did the respirator shift on the male's face, and the shift was minor. The surgical mask was most expandable of the three masks; however, it provided a looser fit and the pleats did not fully retract after the mouth was closed. Air gaps around the perimeter of the surgical mask reduced the overall fit factor. The cloth mask had a visible air gap between the bottom of the mask and the chin for the closed mouth posture, which translated to a poor initial fit. It also had enough clearance for the chin in the open mouth position. While this gapping circumvented the issue of the mask shifting during talking, it was ultimately counterproductive as it allowed for even more leakage during talking.

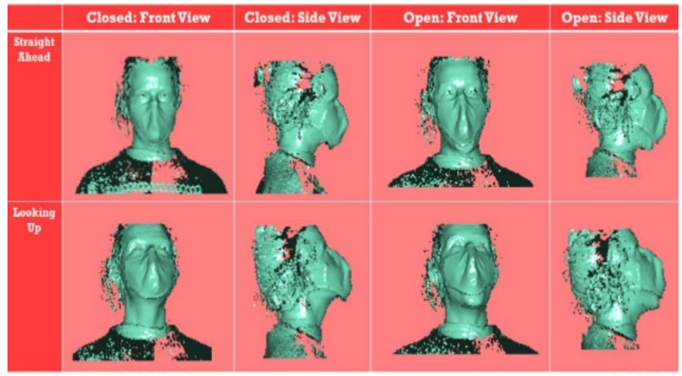

Figure 1. Front and side views of two mouth postures and two neck postures for nonmedical cloth face mask

Conclusion: In this study, we looked at the dynamic fit of commercial face masks by scanning participants in both stationary mouth positions and after completing a standard talking exercise. The findings included methodology development using three commercial face masks and showed visible differences between the N95 respirator, surgical face mask, and cloth face mask. The main mode of shifting after talking was the masks sliding down the bridge of the nose, along with other observations such as gaps between mask perimeter and face and extended pleats not recovering. This study has a few limitations. Three representative, commercially available face masks were tested, but these do not necessarily span the breadth of available face mask designs. Therefore, this study serves as a demonstration of the feasibility of this method and can be applied to a larger participant study to evaluate new cloth face masks that better accommodate the action of talking. The 3D head scans of the open mouth position can also be used to virtually drape new mask designs.

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