



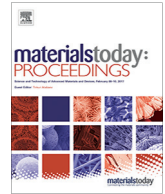
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Collaborative manufacturing of ergonomic personal protective equipment (PPE) accessories to prevent infectious disease

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ABSTRACT

Throughout history there have been epidemics and pandemics of all kinds, however the most recent ones have been respiratory diseases that have had a significant effect on the society and that have caused high mortality rates. The preventive measures to minimize the risk of contagion by contact with infected surfaces include ergonomic accessories including personal protective equipment (PPE) to prevent hands to be in contact with surfaces that could be infected by viruses, bacteria, fungi, etc., thus avoiding infection by the usual entry routes (mouth, nose, and eyes) to the human body of highly contagious diseases such as COVID-19. The collaborative manufacture of these safety accessories at the site of consumption is a current option that minimizes infectious diseases and reduces costs. Accessories such as the so-called “ear saver” and “anti-contact keys” can be produced by 3D printing with a general CAD/CAM and allow users in hospitals, and schools, such as medical and teaching staff and society in general to extend the life of N95 respirator fasteners (protective masks) and avoid contagion. These devices can be used to open doors and windows and control elevators, etc. The accessories can be optimized ergonomically for individual use by providing a custom design. The collaborative manufacture of these elements allows the product design stages to be carried out autonomously. In the manufacturing stage, 3D printers can be used to produce the devices at the point of use, thus saving on transport and distribution costs. This paper describes a comparative analysis of their design, manufacture and use in hospitals, schools, universities, and commercial areas with the aim of improving the current design.

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1. Introduction

The need to manufacture products on the consumer's premises is a possible alternative to improve response times for the high demand when products are in short supply. The COVID-19 pandemic showed the need to have response plans and products available at consumer sites, since when there is a need for masks and other personal protective equipment (PPE), selling prices are often excessive due to the high demand. To improve comfort when wearing masks such as the N95 we have the so-called “ear saver”, and to minimize contact with possible infected surfaces, “anti-contact

keys”, which are innovative products that can be manufactured locally by means of 3D printers [1].

The existing PPE accessories on the market can be improved thanks to collaborative manufacturing since this allows users to adapt them to their own needs. The use of 3D printers during the first wave of the pandemic had a significant effect on providing the face masks which were urgently required to avoid contagion. This encouraged the use of rapid prototyping 3D printers for manufacturing articles at the place where they were needed [2,3]. Therefore, large companies worldwide began solidarity projects to disseminate information on the manufacture of different elements by making their *.slt files available [4]. In this process printing speed and economic aspects must be considered [5,6]. The World Health Organization (WHO) declared a “public health emergency” in January 2020 [7] including the need to determine the

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best products to satisfy the latent needs. Accessories such as “ear savers” are useful as they prevent ear fatigue when masks are worn for long periods. “Anti-contact keys” are useful to avoid touching contaminated surfaces, and aerosols can be sources of contagion and require preventive measures [8] since there is a greater risk of contagion in public spaces Fig. 1 shows how the mask is used during the working day when complemented with a device called the “ear saver” that minimizes the strain on the ears and facilitates the wearing of glasses, headphones, or other accessories.

Complementary to this, to open doors and windows we have the device shown in Fig. 2, known as the so-called “Anti-Contact Key”, which minimizes direct hand contact with surfaces potentially infected by aerosols containing viruses [9]. In Spain for example, different proposals have been made for anti-contagion keys, for example Proto&GO and i-mas (<https://www.protoandgo.com/lave-anti-covid/>) who make the *.slt file available to those who have a 3D printer to manufacture their devices.

Manufacturing accessories in collaborative environments allows the product design stages to be carried out autonomously. In the manufacturing stage, the options include 3D printing, which is a good alternative since it means products can be manufactured at the site where they are needed, thus allowing savings in marketing, transportation, and distribution. There are also several fused deposition modeling (FDM) manufacturing techniques in contrast with stereolithography (SLA) and others that require a cleaning procedure [10,11]. PLA is a widely used material in 3D printers



Fig 1. Use of “Ear saver” in Telework activities.



Fig 2. Example of an “Anti-Contact Key”.

and research indicates that its volume can vary during the cleaning or sterilization process [12].

Open-source models can be found on the web and are also available for manufacture. The main uses of the “anti-contact key” include:

- As a pushbutton for ATMs, elevators, and switches in general.
- For sliding and rotating pistons
- For opening doors and windows
- To avoid using the hands to open or close doors.
- Can be used as a keychain.

Reviewing different proposals available on the web, we found that there is a wide variety of products and accessories for PPE. It is important to disinfect these accessories after use, i.e., to clean them immediately after use either by immersion or by spraying with a bleach solution (1 part bleach and 50 parts water) or alcohol at a minimum concentration of 70%.

2. Materials and method

The PPE accessories (ear saver and anti-contact key manufactured by plastic injection) were evaluated in the stages of the product life cycle (design, manufacture, use and end of life), so that a process reengineering could be carried out. To achieve this, we initially relied on evaluated and improved commercial designs.

In the first stage of the study, we focused on the use phase since it was of interest to evaluate existing products to improve them and obtain collaborative feedback to generate a model that fitted needs. Table 1 summarizes the objectives set for each stage of the product life cycle.

As the PPE accessories that analyzed in this study as a concept were already on the market our intention was to improve them after carrying out an analysis of their advantages and disadvantages. An evaluation of the life cycle of the different accessories selected was carried out and improvements were proposed to adapt them to the client’s needs, since when a PPE is acquired, adjustments are often required to adapt the ergonomic criteria to the real conditions of use, i.e., correct implementation and use.

In each of the life cycle phases of PPE accessories we analyzed the advantages and disadvantages to improve future products.

Table 1
Objectives of each stage in the life cycle.

Phase	Objectives of each stage in the life cycle
Design	Simulation of manufacturing processes to obtain parametric models
Manufacturing	Selection according to process alternatives
Use	Adaptable to the installation where it is used.
End Of life	Care of the endowment recyclability

Collaborative manufacturing is associated with the product life cycle, in which the different stages must be considered to obtain a product that meets the most demanding requirements.

This means the analysis must focus on the 4 different stages and consider different points of view from experts and users to fully meet the requirements. In our study we considered two products that were already on the market and how they could be improved: the ear saver and the anti-contact key, which are accessories that minimize the risk of contagion, taking into consideration that:

- a) The ear saver makes wearing masks for long periods more comfortable.
- b) Anti-contact keys are used to minimize contact with surfaces that could possibly be contaminated displayed equations are centered and set on a separate line.

2.1. Evaluation in the use stage

For the evaluation of the accessories in the use stage, a group of 27 people (L_{27}) were selected who work in educational and health entities as being likely to be at risk. The selection criteria were based on groups that may have to spend many hours wearing masks and gloves to minimize their risk of contagion. The orthogonal array L_{27} was selected because it allows us to carry out studies with more parameters that can be incorporated in future research, since statistical analyzes can be carried out with 27 tests on 13 factors with 3 levels, which gives it a great coverage.

2.2. Visual analogue scale (VAS)

Recent studies on face shields used the VAS technique [1] to identify their effectiveness. Of the 27 people in our sample, 8 worked in the health sector (30%) and 19 in the education sector (70%). These were provided with the accessories to test for a week, after which they were asked to respond to a questionnaire that had the following criteria: (1) fit, (2) comfort, (3) use, (4) protection, and (5) full evaluation of the accessory.

The fit (1) had to do with the accessory's ergonomics and how it fitted the user. Comfort (2) was the degree of user satisfaction, use (3) was its versatility, (4) was the degree of protection it provided, and (5) was a global assessment of its use.

The assessment was made on a scale from 0 to 100, 0 being completely unsatisfactory and 100 totally satisfactory. In addition, recommendations were compiled to improve subsequent designs. The tabulated data was analyzed and calculated using the box plot technique to represent the data behavior. Each question included a field for the evaluation of the device's advantages and disadvantages. This information is also dealt with below in the Results and Discussion. It is important to note that the subjects in the study were previously completely unfamiliar with the use of these accessories.

3. Results and Discussion

The evaluation of the PPE accessories allowed us to obtain the scores shown in the following tables. In general, the accessories were very well received since they were novel and useful when wearing masks for long periods. For manufacturing the PPE accessories, some characteristics of these materials can be consulted in Granta EduPack® for the sustainable selection (see Table 2).

3.1. Ear saver

The ear savers were found to be useful to prevent ear fatigue as the masks were no longer supported by the ears but by the ear

Table 2
Some Characteristics of the materials for 3D Printing. Source: Granta EduPack®.

Material	ABS	PLA
Sterilizability (Ethylene Oxide)	Good	Excellent
Sterilizability (Eradiation)	Good	Good
Sterilizability (Steam autoclave)	Poor	Poor
Recycle	Ok	Ok.
Biodegrade	Ok	Ok

savers. The use of glasses, headphones, earrings, and other accessories can also put a greater load on the ears. In addition, the elastic of the masks can begin to stretch, so that the tension can be adjusted by means of the different bars on the ear saver. Fig. 3 shows the different ear saver options manufactured by 3D printing with PLA material in different colors. On the other hand, Fig. 4, shows an ear saver manufactured by plastic injection in use. Plastic injection is feasible for large production batches (The cost of the injection mold must be considered in calculating the unit cost).

Table 3 summarizes the evaluations of the 27 members of the evaluation group. The 5 criteria previously defined in the Methods section were quantified using a visual analogue scale (VAS). Table 4 gives the statistical values of the analysis for the ear saver, where: The following Table 1 gives a summary of all heading level: MIN represents the minimum evaluation; Q1 the first quartile in which the data is found; Q2 the second quartile in which the data is found; Q3 the third quartile of the data; MAX the maximum evaluation; It should be noted that Q2 is the average score.

For the box plot analysis, we used MATLAB to organize the information and to analyze and generate the graphs. Fig. 5 shows the boxplot of the 5 criteria evaluated. In general, the scores were over 94%.

The users made the following evaluations: Variety of colors, 100%, (27/27); Fit, 92%, (25/27); Item cost, 88%, (24/27); Type of material, 52%, (14/27); Use with double mask, 52%, (14/27). These criteria were analyzed by the collaborative group to improve the design and the product.

3.2. Anti-Contact Key

Although gloves have been used to avoid contact with possible contaminated surfaces, recent studies have shown they could in fact increase the risk of contagion if not used correctly. Under this consideration, the use of personal anti-contact keys has taken on greater interest, and several options are now available on the mar-



Fig 3. Example of "Ear Saver" made by 3D printing.



Fig 4. Example of “Ear Saver” made by plastic injection.

ket made of different materials. Fig. 6 shows the anti-contact key being used.

Table 5 summarizes the tabulated data for the anti-contact key accessory, which has been well received by consumers. Its main use is for opening doors, operating switches, valves, ATMs, elevator buttons and push buttons in general.

Table 6 gives the statistical values of the analysis for the ear saver, where: MIN represents the minimum evaluation; Q1 the

Table 3
VAS: Ear Saver.

Test	Fit	Comfort	Wearing	Protection	Total
1	98	97	94	90	89
2	80	86	89	80	84
3	85	95	89	95	85
4	89	96	95	98	92
5	90	95	96	85	96
6	84	95	95	95	93
7	90	98	98	98	92
8	95	96	96	96	96
9	96	92	92	92	94
10	89	93	93	93	93
11	86	95	95	95	92
12	89	98	98	98	98
13	90	96	96	96	95
14	92	89	95	96	98
15	96	86	80	89	96
16	95	89	86	86	92
17	80	90	95	89	93
18	86	92	85	90	95
19	95	96	96	92	98
20	85	95	95	96	96
21	83	80	80	95	85
22	91	86	86	80	95
23	92	95	95	86	98
24	96	85	85	95	93
25	86	85	83	85	96
26	85	98	91	97	95
27	93	90	93	90	90

first quartile in which the data is found; Q2 the second quartile in which the data is found; Q3 the third quartile of the data; MAX the maximum evaluation; It should be noted that Q2 is the average score.

The boxplot analysis was also carried out on MATLAB software to organize the information and analyze the graphs. Fig. 7 shows the box plot for the 5 criteria. The accessory was given an average score of over 93%.

The following aspects were considered: Variety of colors, 100%, (27/27), Use for touch screens 88%, (25/27), Item cost 88%, (25/27), Carrier case 88%, (25/27), Size for round handlebars 88%, (25/27), Type of material, 52%, (14/27).

4. Conclusions

Personal protective accessories are very useful since they allow the main PPE Personal Protective Equipment to be carried around more comfortably. This paper evaluates products that are already on the market to improve and optimize them. Fig. 8 shows a comparative table of the evaluation of the two accessories, which in general were well received since they are new products that can be personalized.

The results were analyzed by the product reengineering group to generate collaborative improvement alternatives.

4.1. Evaluation PPE accessories

As the accessories described minimize the risk of contagion their use was generally recommended by the evaluators. Table 7 shows the average scores of the evaluations, with a total score of 93.3% for the ear saver and 91.1% for the anti-contact key.

The general opinion of the evaluators was that it allowed the use of masks in a safer way and took the pressure off the ears. It should be noted that 70% (19 of 27) of the participants wore glasses and indicated that they felt more comfortable when carrying out their activities.

It was also considered that being able to personalize the products was a distinct advantage. The lowest evaluation given to

Table 4
Statistics of the evaluation of the Ear Saver.

	Fit	Comfort	Wearing	Protection	Total
MIN	80	80	80	80	84
Q1	85	89	86	89	92
Q2	90	95	94	93	94
Q3	95	96	95	96	96
MAX	98	98	98	98	98

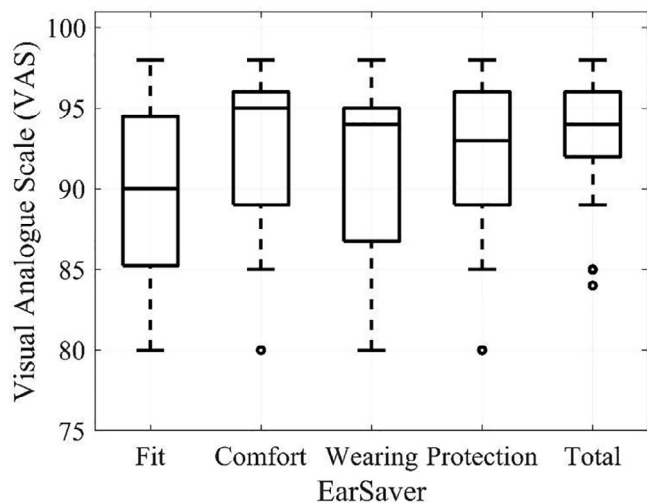


Fig 5. Ear Saver Boxplot.



Fig 6. Example of Anti-Contact Key uses.

the ear saver was by the participants with long hair, who formed 60% (16 of 27) of the group.

The lowest score given to the anti-contact keys was because 55% (15 out of 27) considered that the accessory should be more compact in size.

4.2. Recommendations

Observations and suggestions were also compiled to be considered in the re-engineering of the products. An analysis of the answers and suggestions was made, and the following recommendations were made for the Life Cycle Assessment (LCA) of the PPE accessories in the different phases (see Table 8).

For the Ear Saver:

- a) Comfortable for use by people with long hair.
- b) Different sizes to suit all ages.

For the Anti-Contact Key:

- a) As door handles are not standardized, the design must consider the characteristics of the facilities.
- b) Should be adaptable to touch screens.

To carry out these modifications and changes the parametric model was generated using CAD platform, on which the requirements for analysis were compiled. It should be noted that for the manufacture of these accessories and the definition of the parameters, a preliminary analysis of the group in which it is to be applied should be carried out to define the appropriate parameters: e.g., for the ear saver: age, height, hairstyle, etc.

For the Anti-Contact Key: analysis of the facilities of the buildings to define the range of diameters of types of door locks and accesses and any other facilities involved.

5. Future work

With improved designs and obtaining the parametric models, different materials can be tested in 3D printers, such as ABS, PLA, Nylon, or eco-friendly materials and could lead to significant improvements. This project seeks to promote manufacturing at the point of consumption using locally produced eco-friendly materials.

Is important to note that plastic injection manufacturing is more economic and profitable when big batches are produced for non-customized products. On the other hand, manufacturing by 3D printing with materials such as PLA, ABS or others, is not economic but it offers the possibility to customize products that meet anthropometric ergonomic requirements and medical features.

CRediT authorship contribution statement

César Ayabaca: Conceptualization, Data curation, Writing - original draft, Resources, Investigation. **Carlos Vila:** Supervision. **Salvatore Reina:** Visualization, Investigation. **Ana Medina:** Visualization, Investigation, Writing - review & editing. **Mario Cesén:** Visualization, Investigation. **Marco Carrión:** Resources, Investigation.

Table 5
VAS: Anti-Contact Key.

Test	Fit	Comfort	Wearing	Protection	Total
1	98	97	94	90	89
2	80	86	89	80	84
3	85	95	89	95	85
4	89	96	95	98	92
5	90	95	96	85	96
6	84	95	95	95	93
7	90	98	98	98	92
8	95	96	96	96	96
9	96	92	92	92	94
10	89	93	93	93	93
11	86	95	95	95	92
12	89	98	98	98	98
13	90	96	96	96	95
14	92	89	95	96	98
15	96	86	80	89	96
16	95	89	86	86	92
17	80	90	95	89	93
18	86	92	85	90	95
19	95	96	96	92	98
20	85	95	95	96	96
21	83	80	80	95	85
22	91	86	86	80	95
23	92	95	95	86	98
24	96	85	85	95	93
25	86	85	83	85	96
26	85	98	91	97	95
27	93	90	93	90	90

Table 6
Statistics of the evaluation of the Anti-Contact Key.

	Fit	Comfort	Wearing	Protection	Total
MIN	80	80	80	80	80
Q1	85	86	89	86	87
Q2	89	95	94	92	93
Q3	93	96	95	96	96
MAX	96	96	98	98	98

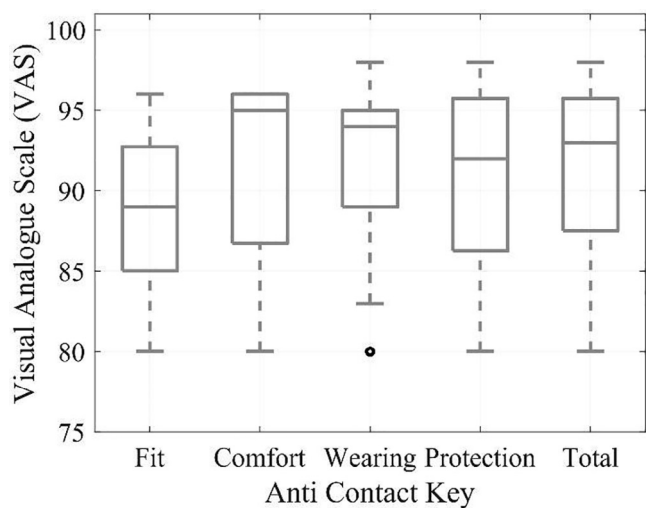


Fig 7. Anti-Contact Key Boxplot.

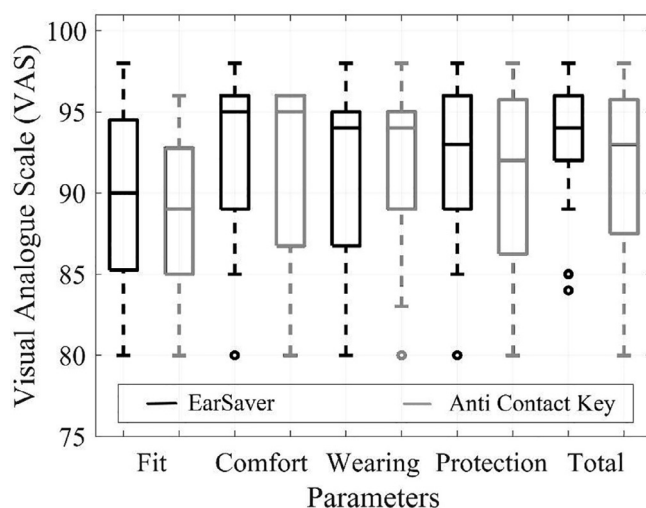


Fig 8. Comparative Boxplot of the PPE Accessories.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 7
Evaluation of the PPE Accessories.

	Ear Saver	Anti-Contact Key
Fit	89.5 $\sigma \pm 5.1$	88.9 $\sigma \pm 4.7$
Comfort	92.5 $\sigma \pm 4.9$	91.7 $\sigma \pm 4.9$
Wearing	91.5 $\sigma \pm 5.4$	91.7 $\sigma \pm 5.3$
Protection	91.7 $\sigma \pm 5.3$	91.1 $\sigma \pm 5.4$
Total	93.3 $\sigma \pm 3.9$	91.1 $\sigma \pm 5.1$

Table 8
LCA for the PPE Accessories.

	Ear Saver
Design	Simulation of manufacturing processes and obtaining an adjustable CAD/CAM parametric model.
Manufacturing	The user can produce the articles on site by 3D printing and generate *.slt
Use	Resistant to wear and tear
End of Life	Uses biodegradable and environmentally friendly material.

tion of Vibrations and Energy Efficiency of Automotive and Aeronautical Transport Systems”, for the assistance received in this project.

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