Design of an accessory dedicated to the manipulation of smartphones measured through myoelectric signals

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Abstract. This research aims to design and develop a product for the charging and handling of smartphones, which reduces the symptoms of the carpal tunnel at the time of using the selected prototype and which can be revalidated by means of myoelectric signals. In the first stage, the method presents three different designs modeled in specialized three-dimension software, dedicated to managing the lifecycle of new products. In the product lifecycle management process of industrial design, the manufacture of the three designs was obtained by going through a posture analysis with the simulation of one of these designs, such as the accessory version three prototype, this being the selected version of the computer aided design, computer aided manufacturing, computer aided engineering, which beat the hypothesis of this research work. The accessory version three of the prototype supports the three aspects expected in this study, the first and most important the physiological aspect; due to the fact that it allows to use the telephone in a healthy way, minimizing the symptoms or tension of the carpal tunnel, the functional analysis was validated by making comparisons with the results of the different superficial electromyography shots applied to the hand of a patient, holding or manipulating each one of them accessories (accessory version three vs. accessory on the current market) and the smartphone, the second technological aspect; because the prototype offers a safe charging station or stage and finally the functional aspect; because it is an innovative prototype and has versatility in the use and handling of Smartphones as a new product.

1. Introduction
Carpal tunnel syndrome (CTS) is widely identified as the costliest musculoskeletal condition of the upper extremities among working-age patients [1]. It is a compressive lesion of the median nerve, located at the wrist level, of traumatic-cumulative disorder characterized by numbness and tingling in the hand and forearm, this nerve allows mobility and sensitivity of part of the hand. Repeated hand and wrist movements increase the risk of CTS [1]. The significant advance of the current market with respect to the mass acquisition and manipulation of smartphones, affects a theme so common that most people, even children from an early age, acquire and manipulate these devices.

Analyzing the global behavior after the consequences of the first year of the Covid-19 pandemic, most people spend more time using or manipulating computers and smartphones due to teleworking and the social isolation imposed by the governments of the world. At the time of acquiring a smartphone, for any person there will be some probability in its manipulation that the user begins to suffer from the symptoms of CTS or increase the ailments of the condition. In the current market there is a diversity of products that help maintain a good posture in the fingers of the hand to properly
manipulate a smartphone in the subject associated with minimizing the symptoms of CTS such as accessories called "Popsocket".

The research work requires implementing strategic innovation and a good systematic literature review when applying search tools in the Scopus web database [2]. The state of the art described was complemented with a process of analysis of trends on the subject using the software tool to build and visualize bibliometric networks VOSviewer® [3]. The search equation of interest is taken and the VOSviewer® tool was implemented, obtaining the following bibliometric network maps associated with the keywords and the other map associated with the related authors. Considering the search equations implemented, a sweep was made of the state of the art from the incidence of CTS in computers, accessories and finally in smartphones.

An Indian study on computer use states, CTS is one of the most reported nerve entrapment syndromes; there are almost 10 million cases present in India alone. Women were also found to be affected more frequently compared to men. Vital symptoms associated with CTS, such as wrist pain, numbness, weakness, can cause impairment in daily activities [4]. Strategies to prevent CTS in the workplace include interventions such as ergonomics, education, exercise, physical therapy, and occupational health [5]. In 2021 a study done in China, work-related musculoskeletal disorders among office workers are of interest to researchers due to a growing incidence, wrist and musculoskeletal discomfort of the hand affected by 15% of occupational groups, including office workers, nurses, and others [6].

According to M Spitzer, 2019 in his research study conducted in Germany states, several studies published internationally in recent years show that intensive use of smartphones can cause pain and numbness in the area of the fingers and hands, the cause is carpal tunnel syndrome known for a long time [7]. A study conducted by A Osailan in 2021 indicates that despite the structure and design of smartphones that allow the use of both hands, young people prefer one-handed use; the use of one hand is mainly based on the movement of the thumb to reach the keys to press, while the rest of the hand is used to grip. The use of smartphones has become a necessity for everyone in their daily life; in recent years, there has been a steady increase in the number of people using smartphones.

In 2020, the number of smartphone users worldwide had been projected at 3.5 billion, 9.3% more than in 2019, this increase in the use of smartphones led to addiction behaviors to these devices, especially in 50% of adolescents [8]. Another study carried out in Japan, the average time of internet use by "mobile devices" was 85.4 minutes on weekdays and 99.4 minutes on holidays, the average time of use of "mobile devices" in the adolescence is extensive [9]. Another current case study in Turkey says that the smartphone addiction has an adverse influence on hand function and pinch strength. Young people should be aware of the harmful effects that can result from excessive use of smartphones [10]. At present, there are research antecedents on this subject related to products that contribute to improve the symptoms of CTS by manipulating a smartphone in relation to the use of computers.

According to the scientific information cited in this study, there is no portable accessory for smartphones on the current market that have been developed from geometric and medical parameters aimed at reducing the risks in handling, leading to physiological and functional aspects related to the pathology of carpal tunnel syndrome. For this reason, a solution was given through the design and manufacture of a prototype developed for the manipulation of smartphones, integrating the physiological and functional aspects.

The test accessory minimizes the symptoms of carpal tunnel syndrome when manipulating the smartphone, work that materialized through the manufacturing in polylactic acid (PLA) with carbon fiber of the design developed where the appropriate positions of the fingers of the hands of an avatar were simulated in the computer aided three dimensional interactive application (CATIA) and to demonstrate the physiological benefit, the prototype was subjected to a more in-depth study with superficial electromyography tests performed on a woman older than 30 years at the "clínica Las Vegas", Medellin, Colombia.
2. Materials and method

According to the stages described in the holistic research methodology by Jacqueline Hurtado de Barrera, the methodology used in this study is part of projective research [11]. The main objective of this research is to propose a new prototype that supports the physiological, technological, and functional field in the use and manipulation of smartphones to minimize the symptoms of CTS. To create a proper accessory design, it is important to understand the fundamentals of the anatomy and physiology of the human hand [12]. A successful accessory model could be produced by observing and understanding the shape and work of the human hand [12].

In this method, we started from the conception of the industrial design of three versions elaborated in this work in relation to a product or prototype that is used for the healthy handling of smartphones. The first two versions (AV1 and AV2 prototype) did not fulfill the physiological aspect in meeting the primary need to minimize the symptoms of CTS (Figure 1(a) and Figure 1(b)); therefore, they were not of interest to the results of this investigation. In the design modifications of the AV3 prototype (Figure 1(c)), a geometry was defined that had to reach some angles in the new grip of the product and the smartphone, a position that favored and was simulated, reaching the objective of minimizing the symptoms of CTS, using the tool (human builder) in CATIA V5.

2.1. Developed designs

In the method applied to design we enable the management of the life cycle of new products, product lifecycle management (PLM) to guarantee the best development and manufacturing. Three-dimensional printing (3DP) is touted as a central element of a new industrial revolution, in which digitization, information and connectivity transform product innovation [13]. This part of the manufacturing procedure called rapid prototyping was the means to achieve 3D prints of the developed prototypes, as can be seen in Figure 1.

![Render images of the designs developed, (a) prototype AV1; (b) prototype AV2; (c) prototype AV3.](image)

2.2. Anatomical posture analysis

The result of the design of this prototype is subjected to simulation for the control and validation of the correct angles of the openings of the fingers and the wrist of the hand (critical angle), in the ergonomics design & analysis module of human builder in the CATIA V5 tool, see Figure 2. According to the analyzes carried out on the CTS and considering the correct or adequate posture to manipulate the smartphone, it is not possible to generate angles in the wrist that compress the nerves that pass through the carpal tunnel to avoid tingling or numbness. This angle should not exceed 8° of wrist flexion as a first indication to control the correct angles, in the same way the opening angles of the phalanges are analyzed, and it is discovered that the angles between phalanges should not the joints closest to the hand exceed 80° and the following joints do not exceed 20° and the last joints 10°.
Figure 2. Perspective views, posture analysis in the human builder of ergonomics design & analysis module, CATIA V5.

2.3. Prototype manufacturing
After simulating the correct postures of the hand, the AV3 prototype was printed using acrylonitrile butadiene styrene (ABS) material, initially tests were carried out manipulating the prototype with this material and later other prototypes were printed with translucent PLA material, this in order to compare the behavior of the two materials, noting a better behavior in the PLA material. Immersion precipitation 3D printing (ip3DP) offers the ability to fabricate porous 3D models using inks with wide ranges of vapor pressure and viscosity [14].

2.4. Equipment used
Electromyography (EMG) is a technique to evaluate and record the electrical activity produced by skeletal muscles to see the condition of the muscles [15]. An efficient analysis of EMG signals plays an unavoidable role in the diagnosis of neuromuscular disorders, prosthetics, and several related applications [16]. The equipment used in November 2020 to perform surface electromyography tests and to be able to evaluate the stress behavior of the finger flexors as the last objective of this research was computer-aided design (CAD) WELL-Sierra Summit, model technology to prioritize reliability and efficiency for EMG, nerve conduction study (NCS) and ultrasound needs implemented in measuring the tension of the superficial flexors of the fingers and the flexor of the thumb.

3. Results and discussion
The results obtained throughout the research are shown in the following.

3.1. Verification of the functioning of the prototype
Observing the functionality of the AV3 prototype, it was possible to detect that the design of this version is the most complete and defeats the hypothesis of this investigation. Now we show the list of benefits that this design has in its AV3 version: The master test of this research was carried out, which is to condition the AV3 prototype with the smartphone to minimize the symptoms of CTS, using it in the correct way.

3.2. Validation through electromyography testing of the prototype
A study of the involvement of the CTS in Poland, 2019 states: “compression of the median nerve is often associated with edema of the palmar cutaneous branch of the median nerve (PCMN), a nerve that arises from the radial aspect of the median nerve and runs to along the ulnar aspect of the flexor carpi radials. Irritation of this nerve is a factor causing pain and numbness in the thumb region” [14]. Put the accessory on the job site intended to perform the test, where all EMG surface electrodes on the patient's hand capture myoelectric signals that are manipulated to allow the hand [15] to move. To monitor the impulse, three electrodes (EMG stickers) that read the EMG signal will be placed at [15] different locations on the patient's hand and wrist.
EMG signals are widely used for clinical applications, as well as for prosthetics and rehabilitation [16]. In the procedure of this activity, a patient over 30 years of age was subjected to perform superficial electromyography tests by means of high precision medical equipment and experts in the field. Different tests were taken to measure some the functionality and reliability of the AV3 prototype developed and it was possible to propose through a comparative analysis of the results of the different tests, the validation of the physical prototype.

The carpal tunnel supports the flexor tendons of the superficial and deep parts that are responsible for the fine movement of the fingers and, therefore, for the precise action of the hand. This action is ensured by the activity of the lumbricals and interosseous muscles innervated by the median nerve” [14]. In this case, the tension of the superficial flexors of the fingers and thumb was measured while manipulating a smartphone. Using the technology (Sierra Summit – CAD WELL) of the medical teams of the “clinica Las Vegas” in Medellin, Colombia, the AV3 prototype has been subjected to superficial electromyography tests on the left hand of the patient, where three sensors were connected in the different areas of the wrist and hand to measure the contractions or tensions of the different flexors that pass through the carpal tunnel, as evidenced in Figure 3 and Figure 4.

Until now, many investigations and efforts have been made in this field, for the improvement of algorithms and the development of old methodologies, techniques are also developed to reduce noise and the acquisition of correct EMG signals [16].

Figure 3 and Figure 4 illustrate the result with the graphs of voltage in microvolts (µV) vs time in milliseconds (msec) of both the long flexor of the thumb and the superficial flexors of the fingers of the tested hand, emitting two types of signals on each graph. The upper signal is associated with the real-time record and the lower signal is associated with the accumulated record.

![Figure 3](image1.png)

(a) Registered voltage by holding or manipulating the smartphone only; (b) registered voltage by manipulating the smartphone with an accessory on the current market; (c) registered voltage by handling the smartphone with the AV3 accessory.

![Figure 4](image2.png)

(a) Registered voltage by holding or manipulating the smartphone only; (b) registered voltage by manipulating the smartphone with an accessory on the current market; (c) registered voltage by handling the smartphone with the AV3 accessory.

4. Conclusions
Since 1970, based on Scopus web, research has been carried out on the carpal tunnel syndrome and its influence with the use of computers and accessories according to the bibliometric structure presented in this study and from 2011 to the present, there have been investigations on the carpal tunnel syndrome and its influence with smartphone, showing graphs with an exponential type of traceability in relation to the number of documents published with respect to time.
The result of the superficial electromyography’s generated comparisons in the graphs to validate the nominal conditions of the AV3 prototype at the time of its use, where it is shown that it minimizes or significantly reduces the noise signal recorded from the tension of the flexors in the 5 phalanges, we can carry out a definitive analysis and conclude that the AV3 prototype is above the conditions and the physiological benefit of the existing product in the current market.

The contribution to knowledge is associated with the functional analysis in the testing carried out on the AV3 accessory and the relationship with classical physics focused especially on the wave branch in achieving the generation and interpretation of myoelectric signals through the graphic results thrown in the superficial electromyography tests performed on a woman older than 30 years.

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