

EXPLORING THE USE OF CHATGPT AND DALL-E FOR THE PRELIMINARY DESIGN OF 3D-PRINTED WRIST-HAND ORTHOSES

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Abstract: *The transformative impact of Artificial Intelligence (AI) technology manifests across many fields, among which medicine is a relevant beneficiary, significantly contributing to enhancing patients care through designing individualized treatment plans, diagnostics support, imaging analysis, virtual assistant chatbots, etc. However, AI applications in orthotics realm remain mostly unexplored. This paper investigates the integration of ChatGPT with the DALL-E image generator in the design process of 3D-printed wrist-hand orthoses. The objective was to support design ideation by configuring a custom GPT for this topic and using iterative prompt refinements. A multidisciplinary approach incorporating knowledge from engineering and occupational therapy guided the research. Tests results showed that the model is not able yet to generate consistent modifications based on requests, challenges being identified relating to the difficulty of addressing the highly variable orthotic needs. In this sense, a dedicated AI application is required, capable to use multidimensional data and to integrate patients' feedback into the design loop. Nonetheless, features of the proposed designs showed the potential of ChatGPT to support design-related brainstorming for the development of custom medical devices, presenting an innovative solution to be used in practice.*

Key words: *ChatGPT, DALL-E, prompt engineering, iterations, design, orthotics, 3D printing, splints.*

1. INTRODUCTION

The use of Artificial Intelligence (AI) in healthcare spans radiology, diagnosis, imaging, personalized treatment plans, drug development, health monitoring, as well as rehabilitation education, management or implementation of virtual assistant chatbots for patients and medical personnel, etc. [1–4]. Therefore, the variety of AI tools ranges from resource allocation, predictive analytics and pattern recognition applied to medical data to the use of large language models (LLMs) for generating patients reports [5], analyzing the medical literature [6] or supporting the clinical decisions [7]. The main benefits of AI refer to its efficiency in processing large volumes of data in a short period of time, thus accelerating the diagnostic process based on informed decisions, reducing costs by automating administrative tasks, minimizing human errors, enhancing the accuracy of treatments, and tailoring healthcare to the patients' individual needs [8].

The use of AI in specialized fields such as prosthetics and orthotics to improve assistive devices functionality is less documented, with only several reported types of applications for recognizing and analyzing movements' pattern of myoelectric prostheses [9], performing gait analyses from data gathered using smart insoles [10], or ensuring electromyography signals control of machine learning-based upper-limb actuated orthoses [11]. Despite AI's mentioned benefits, its applications in

orthotics remain mostly unexplored. In this context, this study investigates whether ChatGPT (OpenAI, USA), a renowned natural language processing (NLP) model, can effectively aid in designing wrist-hand orthoses for 3D printing. The goal is to support the design ideation and customization by incorporating multidisciplinary requirements. The approach involves collaboration among experts in design, engineering, ergonomics, and orthotics, promising significant improvements in device customization and functionality.

Comfort and aesthetic of orthotics devices (in this study, splints for upper-limb) represent powerful factors for increasing adherence to usage. Patients often prefer 3D-printed customized orthoses for their lightweight construction and better ventilation compared to traditional casts or braces [13]. Although extensive research has focused on design aspects, 3D printing processes, mechanical testing, and clinical trials [14–15], these innovative medical devices have yet to become adopted in clinical practice. By using natural language processing, ChatGPT has the potential to effectively capture therapists' design ideas and translate them into design and engineering specifications. This novel approach, not previously reported, aims to enhance collaboration between hand therapists and engineers, thereby accelerating the development and adoption of customized orthotic solutions.

A custom version of ChatGPT was specifically trained to support the design of orthotic devices. Using best practices in prompt engineering [12], along with iterative refinements and the use of the DALL-E image generator, the approach allow studying the generation of

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various design proposals. These were then critically evaluated by orthoses designers, providing structured feedback for functional and improved designs. Consequently, the ChatGPT's potential as an innovative tool in rapidly iterating and refining custom orthotic solutions was evaluated.

2. MATERIAL AND METHOD

2.1. Experimental methodology

Figure 1 presents the research methodology applied in the investigation.

A custom version of ChatGPT, named *orthosis_GPT*, was developed to assist in generating preliminary designs for wrist-hand orthoses, incorporating the general specifications presented below. Following the initial output in terms of design and written specifications, the subsequent prompts are to be tailored based on the specific responses received, allowing for iterative refinements of the splint's design. It is important to note that each interaction with the model resulted in a different initial design, thus necessitating customized follow-up queries to align the provided output with the targeted splint model. Consequently, the Results section will only present the most significant prompts and their corresponding outputs, rather than a comprehensive list of all interactions.

Splint general specifications were the following:

- Volar splint (sustains the volar surfaces of the forearm and the palm);
- No locking mechanism, splint adjusted on the hand and forearm using three Velcro straps placed in the forearm zone, palm zone and wrist zone;
- One material for the orthosis, namely PLA;
- Ventilation pockets and slim design;
- 2/3 of the forearm length;
- Fingers and thumb free to move.

This information was input in *orthosis_GPT* model respecting prompt engineering format of clearly defining role, context and tasks:

- Initial Prompt/query: *"I need a volar splint, subsequently to be 3D printed. The splint should be made only from one material, PLA. The design should include no other locking mechanism than three Velcro straps to adjust the splint's fixation on the human hand. The straps are placed around palm, wrist and forearm. Splint does not exceed the MCP joints to let the fingers free to move. Splint length is 2/3 of the total length of the forearm. Show me the splint isometric view and 2D views from different angles. The splint design should include pockets for ventilation, be lightweight, and not totally encircle the hand and forearm."*

This first query was input into *orthosis_ChartGPT* to assess the impact of GPT personalization and specific knowledge database on the relevance of the answers –

section 2.2. The iterative design process involved requests formulated by an engineer and an occupational therapist (roles) – section 2.2. Then, the same initial query was input to ChatGPT, and results were compared in terms of relevance – section 2.3.

2.2. ChatGPT configuration for *orthosis_GPT*

With ChatGPT 4.0, users have the possibility to customize their own GPT to address a certain topic and to tailor the model's answers closer to the needs, thus creating a specialized AI assistant. By setting criteria in the Configuration tab (Fig. 2), the model should be able to focus on a particular area of interest, including Conversation starters, in this case related to wrist-hand orthoses design. Such a GPT was configured for this research as follows (only the main aspects are mentioned here):

- **Scope and depth:** Focuses on the specific topic of 3D-printed wrist-hand orthoses, providing in-depth information on design, including orthoses images. It distinguishes between splints and casts (casts encircle the forearm), and suggests designs made from a single material. It includes detailed information on the 3D printing process, customization options, and typical materials used.
- **Image Generation:** Generates images of the orthosis placed on a human hand and forearm, and it provides its views from multiple angles, alongside 2D technical or product design drawings or views, isometric view for a comprehensive understanding of the proposed design.
- **Clarification Requests:** In case of ambiguous requests, it asks for clarifications, and only after multiple attempts for a clearer understanding it makes making assumptions based on typical needs and designs, as well as on the design solutions disseminated in the pdf files uploaded in Knowledge.
- **User Feedback Loop:** Implements a mechanism to ask and integrate the user's feedback on the generated designs.
- **Documents:** Uses the documents uploaded in Knowledge, as well as other documents available during training.
- **Personalization:** Maintains a professional tone throughout interactions.
- **Design Versioning:** Keeps track of design iterations if asked to document the evolution of concepts and facilitate comparisons between different versions.
- **Ergonomics and Usability:** Prioritizes the ergonomic aspects of orthosis design to ensure user comfort and functionality. Includes suggestions on fixation modalities, number of Velcro straps, and placement of the forearm.

For image generation, DALL-E generator is used within ChatGPT.

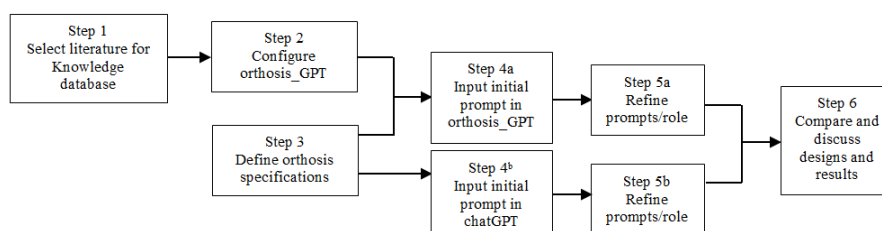


Fig. 1. Research methodology.

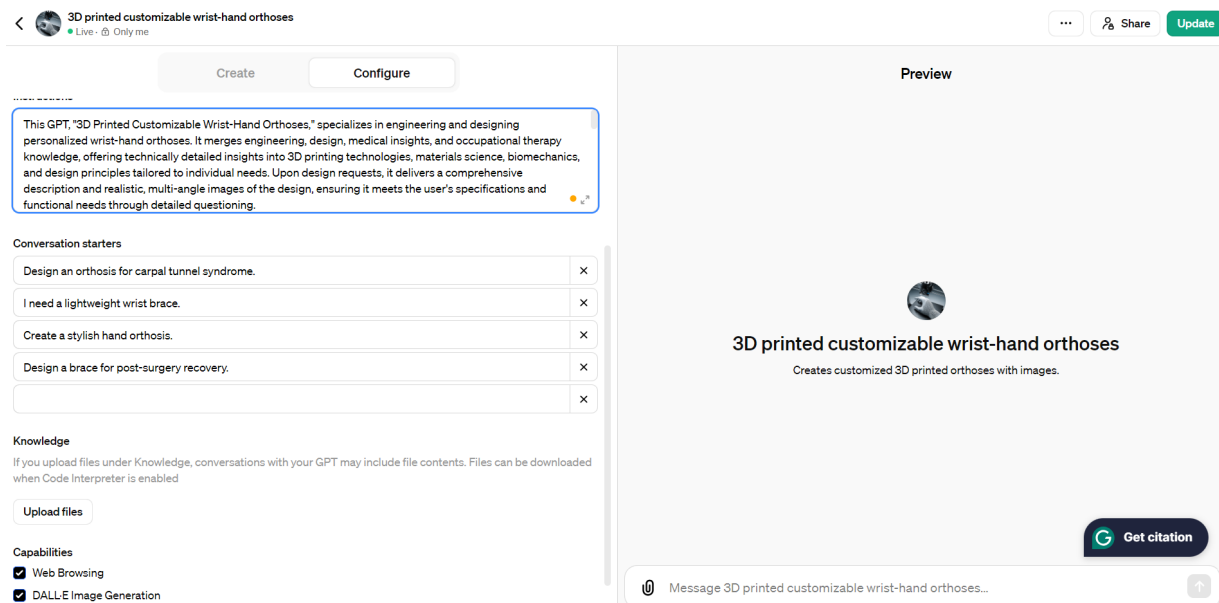


Fig. 2. Configuring a GPT for the specific topic of wrist-hand orthosis design.

2.3. Literature selection for the Knowledge database

To tailor the model's responses, it is possible to upload information using the Knowledge feature. This allows providing relevant context-related and specific information for a particular query or task. Consequently, the model is tuned to offer more accurate information based on the uploaded documents. For this purpose, literature was selected using scientific electronic databases to identify studies focusing on 3D-printed wrist-hand orthoses. Key terms were used to generate specific queries as follows:

- PubMed: "3D printing"[Title/Abstract] AND "design"[Title/Abstract] AND ("orthosis"[Title/Abstract] AND ("hand"[Title/Abstract] OR "wrist-hand"[Title/Abstract] OR "upper-limb"[Title/Abstract]) OR "splint"[Title/Abstract] OR "cast"[Title/Abstract])
- Clarivate ISI Web of Knowledge: (((TS=(design)) AND TS=(orthosis OR splint OR cast)) AND TS=(hand or upper limb)) AND ALL=(3d printing);
- Scopus: TITLE-ABS-KEY ((design AND (orthosis OR splint OR cast) AND (hand OR upper limb)) AND 3d printing)

The retrieved documents were filtered, and only the full-text versions of studies in English were selected for upload into orthosis_GPT.

3. RESULTS AND DISCUSSIONS

3.1. Literature survey results

The following numbers of studies were found based on keywords from the title and abstract: Clarivate – 129, PubMed – 154, Scopus – 109. The exclusion criteria applied were: studies related to dental applications, studies of dynamic splints, and studies without an explicit focus on orthoses' design. After removing duplicates, 59 papers were retained for full text read. Subsequently, the papers which did not provided information on design criteria for wrist-hand orthoses or include images were removed from the pool. Consequently, 42 papers made up the final list. Additionally, images of 3D-printed splints and casts were

retrieved from the internet for use by the model. However, during the upload of these documents into orthosis_GPT Knowledge, update errors occurred and only up to 20 items could be finally included in the database. This represents a current limitation of the Knowledge feature of the model, acknowledged by the developer, up to 10Mb per file [16]. Also, the number of documents is limited by the number of tokens.

In this context, a new filtering was performed, and 20 of the most relevant documents, including PDF files with full papers and images of orthoses, were finally included in Knowledge. The images were named splint or cast, for ensuring that the model can make the difference between them. Moreover, brief information on fixation method using straps and pockets shape (Voronoi, hexagonal, diamond, circle, etc.) was added in images titles for training the model.

3.2. Orthosis_GPT iterative prompts and orthosis design

The initial query was input in the orthosis_GPT and the model provided detailed information on design specifications such as material, fixation, etc. – as requested, and also information on the design process. Analyzing the orthosis development process, the custom steps of 3D scanning the user's upper limb followed by digit model of the orthosis and finite element analysis (extracted from pdf documents), as well as 3D printing process and post-processing were provided. However, the images of the orthosis (Fig. 3) were not those expected, and query refinements were conducted based on roles:

- Refinement step 1:

Engineer: "Update the design you proposed by designing Voronoi like ventilation pockets. Use only one material for the splint, namely PLA." – The result is presented in Fig. 4. The text output is revised to include the changes. However, the splint length does not represent 2/3 of the forearm length. The new prompt will address these requests, while defining a new role and confirming that the design.

1. **Material:** The orthosis will be made from Polylactic Acid (PLA), a biodegradable and bioactive thermoplastic aliphatic polyester derived from renewable resources, such as corn starch or sugar cane. This material is widely used in 3D printing due to its relatively low printing temperature, minimal warping, and non-toxic properties.
2. **Fixation:** The design will include three Velcro strips for adjustable fixation. These will be positioned strategically:
 - * One at the palm area to ensure the device remains snug against the base of the hand.
 - * One around the wrist for secure immobilization.
 - * One near the top of the forearm segment for full encirclement and support.
3. **Coverage and Immobilization:** The orthosis will end at the metacarpophalangeal (MCP) joints, allowing free finger movement. It will cover 2/3 of the forearm, ensuring effective immobilization of the wrist in a functional position while allowing some forearm rotation.
4. **Ventilation:** The design will incorporate hexagonal pockets across the surface, primarily located on the areas covering the palm and the inner side of the wrist and forearm. These will reduce the weight and improve airflow, making the orthosis more comfortable to wear, especially in warm conditions or during extended use.

Design Process:

1. **Scanning and Modeling:** We'll start by obtaining a 3D scan of the patient's forearm and hand. This scan provides the precise dimensions needed for a custom fit, ensuring comfort and effective immobilization.

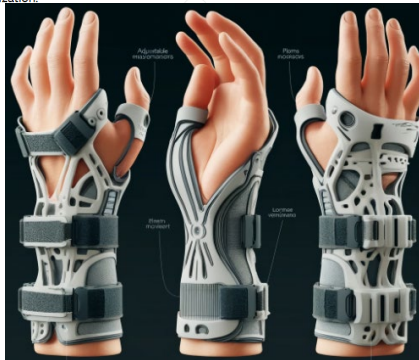


Fig. 3. First iteration of wrist-hand orthosis.



Fig. 4. Second iteration of wrist-hand orthosis with Voronoi pockets and three Velcro straps – engineer’s request.

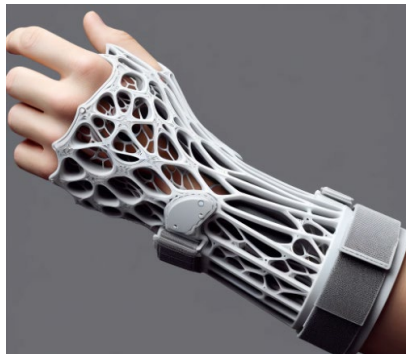


Fig. 5. Second iteration of wrist-hand orthosis with Voronoi pockets and three Velcro straps – engineer’s request.

• Refinement step 2:

Occupational therapist: *“Update the proposed design from the perspective of a hand therapist. The splint must be easy to place on hand and forearm. The length of the splint is 2/3 of the total length of the forearm. The splint should not cover the entire dorsal surface of the forearm.”* The result is presented in Fig. 5.

• Refinement step 3:

Orthosis_GPT is not updating the proposed design, always generating a different version. A specific request was made in this sense for the proposal from Fig. 5. Additionally, the volar splint is supporting the volar surfaces of the hand/forearm and not the dorsal surfaces as in the splints generated by ChatGPT using DALL-E.

Regarding roles, there was no difference in output when engineer or occupation therapist perspectives were requested. Therefore, after the third iteration, no such distinction was made between these roles.

- Prompt: *“I will paste an image. Update the design in that image so that to sustain the volar (interior side) of the hand/forearm.”*

The output was the design in Fig. 6. As noted, despite the specific query, orthosis_GPT failed to refine the splint, resulting in the generation of a new version.

Figure 7 presents the model's response, which confirms that it recognized all the specified criteria and referred to the Knowledge document. However, the design produced still does not meet the criteria.

For making sure that orthosis_GPT is using the documents provided, two prompts were formulated based on the information in the documents:

- Prompt: *“Respond as an engineer. Summarize the results of the documents uploaded in Knowledge. Be specific.”*

- Output: see Fig. 8.

The output showed that model understands where to look for information, though it requires specific instructions to do so effectively. Asked, the language model was unable to retrieve images from the pdf files (Fig. 9).



Fig. 6. Splint design proposed by the model in the third iteration.

You
Generate the design as I requested. Use the images and documents I provided in Knowledge.
< 2 / 2 >

3D printed customizable wrist-hand orthoses
Based on the information and resources provided, I will update the existing volar wrist splint design to ensure that it properly supports the volar side of the hand. The revised design will be optimized for 3D printing in PLA and include Voronoi patterned ventilation pockets for breathability. It will incorporate the necessary fixation points for three Velcro straps, ensuring they are positioned optimally across the palm, wrist, and forearm zones. The length of the splint will correspond to two-thirds of the total length of the forearm, without exceeding the MCP joints to allow free finger movement.

For the updated design, I will use the insights from the documents to integrate ergonomic considerations, as well as structural and assembly features to enhance patient comfort and the functionality of the splint. I'll incorporate a balance of rigidity and flexibility, taking into account limb swelling and providing enough support while maintaining comfort over extended periods.

Fig. 7. orthosis_GPT response to query.

- 3D printed customizable wrist-hand orthoses**
Here are the detailed and specific results from the studies and documents you've uploaded, analyzed from an engineering perspective:
1. **Wong2015.pdf:**
 - The study investigated the use of 3D printing technology to produce custom mallet splints for Mars analogue crewmembers. It successfully demonstrated that custom ABS thermoplastic splints could be printed on-site and used effectively. The key findings include:
 - The 3D-printed splints were produced within a print time range of 21 to 29 minutes per splint.
 - All participants reported that the splints fit securely and comfortably.
 - Functional assessment showed that these splints allowed full active range of motion of the proximal interphalangeal joint (0 – 100 degrees) while maintaining the distal interphalangeal joint in extension.
 2. **Keller2020.pdf:**
 - This document outlines a professional workflow for the in-hospital mass production of 3D-printed devices for hand and wrist rehabilitation. It provides insights into both DLP and FDM 3D printing methods. The specific results highlighted include:

Fig. 8. Results synthesis from the documents in Knowledge.

- 3D printed customizable wrist-hand orthoses**
I found an image of an orthosis from the documents provided. Specifically, the document shows a two-part orthosis that has been segmented for finite element analysis (FEA) testing. Here is a description of the image from the document:
- Figure 3:** This figure presents an orthosis divided into two parts, an upper and a lower section, designed for optimal functionality and structural viability.
- If you need the image displayed or further information on the specifics of the design, please let me know!
- You**
Show it to me
- 3D printed customizable wrist-hand orthoses**
Unfortunately, I can't display the image directly here. However, you can easily access this image by referring to Figure 3 in the 'agudelo-ardila2019.pdf' document from the files you have. This figure will show you the segmented orthosis designed for finite element analysis. If you need help with

Fig. 9. orthosis_GPT output on retrieving images from Knowledge database.

In the next section, the same initial prompt was submitted to the general ChatGPT. In the following queries, attempts were made to refine the splint design.

3.3. ChatGPT iterative prompts and orthosis designs

Figure 10 presents the design generated using the same prompt that tested the ability of orthosis_GPT to be tuned for the specific task of designing 3D-printed splints. Due to erroneous feedback, the request was resubmitted, specifically requesting the isometric view. This adjustment resulted in the image shown in Fig. 11, which was closer to expectations, although it overlooked two very important design criteria concerning the type of splint (volar, not dorsal) or the length, as examples.

Comparing the responses from ChatGPT and orthosis_GPT (Fig. 3 vs. Fig. 8) revealed that the former provided more general information, whereas the latter also considered customization based on a 3D scanning of the forearm, a common approach in the field of 3D-printed orthoses [17]. Further refinements were made, and despite attempts, the desired design was not achieved. However, similar to the experience with orthosis_GPT, some of the suggestions are interesting and could be further applied to the splint design.

The use of ChatGPT in the 3D printing field was reported in [18] to address questions on 3D printers troubleshooting and G-code optimization, showing the model ability to generate accurate answers and, in general, to be a useful tool for engineers. Also, a lot of attention is paid to exploring the use of ChatGPT and other LLMs in medical education or orthopedic research [19]. The current investigation addresses a new field for LLM, namely design in orthotics.

Material and Manufacturing Considerations:

- Material:** The splint will be designed to be printed using PLA, a common lightweight and biodegradable plastic that is ideal for prototyping medical devices.
- Manufacturing:** Consider the limitations and capabilities of 3D printing, such as layer height and print orientation, to optimize the design for printing without support structures where possible.

Let's create the 3D model with these considerations. This will involve drawing the design and preparing the views as specified.

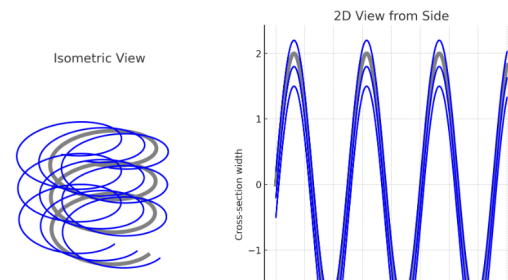


Fig. 10. ChatGPT first iteration of design based on initial prompt.



Fig. 11. ChatGPT proposal for splint design based on prompted criteria.

4. CUSTOMIZED 3D-PRINTED VOLAR SPLINT

From the designs generated by orthosis_GPT through iterative prompting, the models shown in Figs 4, 5, and 11 offered insights into modalities for ensuring the fixation and adjustment of Velcro straps. Previous research demonstrated that flat 3D-printed orthoses [15] not only reduce manufacturing time but also improve flexural resistance. Consequently, the design proposed by the GPT was specifically adapted to this approach, as illustrated in Fig. 12.

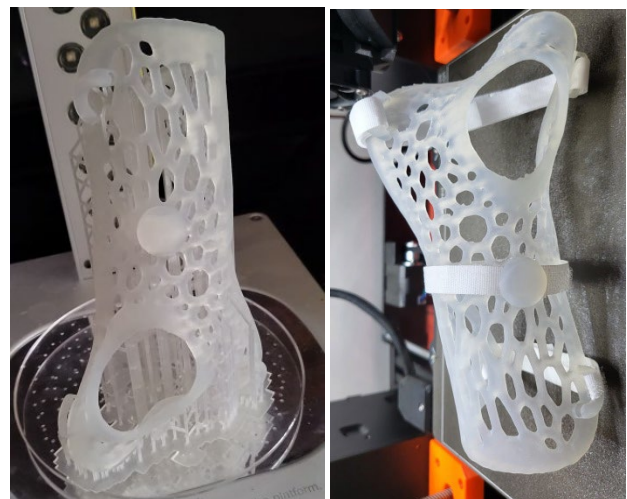


Fig. 12. 3D-printed DLP wrist-hand orthosis.

5. CONCLUSIONS

The study assessed the use of AI tools, specifically ChatGPT with DALL-E, in providing design suggestions and technical specifications for 3D-printed wrist-hand orthoses, revealing their potential for supporting brainstorming and ideation. A critical analysis of the outputs was conducted, as well as a comparative evaluation of results when using ChatGPT and a customized version of ChatGPT configured for the field.

An AI-based application, which can efficiently convey an AI-based application that can efficiently translate specifications expressed in natural language into technical engineering specifications and design suggestions, would be extremely valuable for advancing the field of orthotics. The orthoses design suggestions included features that inspired the final 3D-printed model, Voronoi pockets, Velcro straps fixation features.

The challenges included the generation of a new model for each prompt, despite specific requests for improving existing designs, as well as the current inability to retrieve images from PDFs versions of scientific papers from Knowledge for inspiration, and demonstrated importance of carefully formulating prompts to obtain relevant and good quality information. Custom GPT's ability to include documents to refine model training and focus on specific aspects showed limitations in the number of documents the LLM can currently process. It also highlighted the need to explicitly instructing the model to refer to documents database. However, its effectiveness in analyzing text information and providing relevant responses was clear. Recommendations included customizing orthoses based on 3D scanning of the limb, acknowledging the importance of ergonomic considerations, emphasizing the need for splints that are easy to apply and remove, and addressing biomechanical and durability aspects.

The LLM proved to be a valuable tool for the analyzed application. Further developments are expected to reduce existing limitations, thus transforming the modality through which design tasks are conducted.

Acknowledgement: This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CNCS–UEFISCDI, project number PN-III-P4-PCE-2021-0070, within PNCDI III.

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