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Original Article

Hand exoskeleton for people with mild hemiparesis: a descriptive study on its creation, the first evidence of use and reflections on contributions of occupational therapy

Exoesqueleto de mão para pessoas com hemiparesia leve: um estudo descritivo sobre sua criação, as primeiras evidências de uso e reflexões sobre contribuições da terapia ocupacional

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Abstract

Introduction: Occupational therapists, concerned with avoiding prolonged movement deprivation in individuals with mild hemiparesis, seek to develop and implement techniques that promote neuroplasticity and restore functionality. In addition to procedures used in conventional approaches, robots and exoskeletons have been widely employed in recent decades. **Objective:** To describe the development and results of the initial tests of a hand exoskeleton designed for individuals with mild hemiparesis, highlighting the contributions of occupational therapy in the construction process carried out by a multidisciplinary team. **Method:** The study is organized in two stages. The first presents the context and the theoretical-methodological foundations adopted for the product's development, highlighting the construction process and the contributions of occupational therapy—thus comprising a theoretical-practical phase. The second presents preliminary evidence from the tests of the prototype and its use by two individuals with mild hemiparesis. **Results:** An electromechanical hand exoskeleton was developed, powered by a battery and featuring mechanical traction through a pulley and traction wire system. The tests and preliminary evidence of its use took place through a motor learning program in occupational therapy for individuals with hemiparesis. The results suggest that this is a promising approach, as it facilitates grasping, reaching, and releasing movements, thereby enhancing

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participation in daily occupations. **Conclusion:** This reported experience highlights the actions and contributions of occupational therapy in the collective process of problem-solving and the early-stage development of a hand exoskeleton for individuals with mild hemiparesis.

Keywords: Paresis, Occupational Therapy, Motor Skills, Exoskeleton Device, Equipment Design.

Resumo

Introdução: Terapeutas ocupacionais, preocupados em evitar a privação prolongada de movimentos em pessoas com hemiparesia leve, buscam desenvolver e implementar técnicas que favoreçam a neuroplasticidade e restabeleçam a funcionalidade. Além dos procedimentos utilizados nas abordagens clássicas, nas últimas décadas robôs e exoesqueletos têm sido amplamente empregados. **Objetivo:** Descrever o desenvolvimento e os resultados dos primeiros testes de um exoesqueleto de mão para pessoas com hemiparesia leve, evidenciando as contribuições da terapia ocupacional no processo de construção realizado por equipe multiprofissional. **Método:** A pesquisa está organizada em duas etapas. A primeira descreve o contexto e as bases teórico-metodológicas adotadas para o desenvolvimento do produto, evidenciando os processos da construção e as contribuições da terapia ocupacional, tratando-se, portanto, de uma etapa teórico-prática. A segunda apresenta as primeiras evidências dos testes do protótipo e de seu uso por duas pessoas com hemiparesia leve. **Resultados:** Foi produzido um exoesqueleto de mão de atuação eletromecânica, com fonte de energia via bateria e tracionamento mecânico por polia e fio de tração. Os testes e as primeiras evidências de seu uso ocorreram por meio de um programa de aprendizagem motora em terapia ocupacional com pessoas com hemiparesia, revelando-se um caminho promissor por promover movimentos de preensão, alcance e soltura de objetos, aumentando a participação nas ocupações cotidianas. **Conclusão:** Por meio da experiência relatada, evidenciam-se as ações e contribuições da terapia ocupacional no processo de construção coletiva de soluções para problemas, desde a gênese de um exoesqueleto desenvolvido para pessoas com hemiparesia leve.

Palavras-chave: Hemiparesia, Terapia Ocupacional, Destreza Motora, Dispositivo Exoesqueleto, Desenho de Equipamento.

Introduction

Gary Kielhofner[1], understands occupation as a primary human activity, the result of evolutionary processes that give rise to biological, psychological, and social needs (Veras, 2019). Understanding the human being as an "occupational being" involves reflecting on environmental context, the individual, meaning, purpose, and occupational performance.

[1]Gary Kielhofner, DrPH, OTR, FAOTA (1949–2010) (American Occupational Therapy Association, 2021), together with Janice Burke, developed the Model of Human Occupation, one of the most widely used theories in occupational therapy research and practice. This model provided professionals with a conceptual framework and practical tools to guide their evaluation and reasoning processes, implement change, and measure the impact of interventions. He was a passionate and dedicated mentor, as well as a collaborator with many colleagues. Kielhofner received many of the profession's highest awards and honors, including AOTA Fellow (1983), induction into the AOTF Academy of Research (1984), the AOTF A. Jean Ayres Award (1989), and the Award of Merit (2011).

Stroke survivors face impairments in their everyday life occupations. The long-term consequences, which are generally complex and heterogeneous, may result in difficulties across various domains of functioning (Schepers et al., 2007), such as loss of hand function, which is highly disabling, or sensory deficits, which vary in intensity, area, and modality (Conforto & Ferreira, 2009).

A query conducted in DataSUS—information technology of the Unified Health System (SUS) of Brazil—in 2022 showed 35,982 deaths related to the ICD-10 Group: Cerebrovascular diseases, ICD-10 Category: I64 – Stroke not specified as hemorrhagic or ischemic (Brasil, 2024). According to the *Instituto Brasileiro de Geografia e Estatística* (IBGE), more specifically from the *National Health Survey by level of education and household situation*, 650,625 cases were recorded in Brazil in 2019 of people aged ≥18 years who reported a medical diagnosis of stroke and intense or very intense limitations in their usual activities due to the stroke or its complications (Brasil, 2024). In this context, a specific set of changes in the occupational performance and participation of these individuals can be observed.

Occupational therapists, concerned with avoiding prolonged movement deprivation, seek to introduce training programs and techniques that promote neuroplasticity and restore functionality in its various dimensions (Zilli et al., 2014).

Beyond the procedures employed in conventional occupational therapy programs and approaches, in recent decades, robots—including wearable robotic devices such as exoskeletons (Tavares et al., 2020)—have been widely studied in the rehabilitation field, both as assistive tools in occupational therapy interventions and for independent use at home (Vidrios-Serrano et al., 2018; Yamakawa et al., 2023), particularly with the aim of improving movement performance and promoting greater independence and autonomy in activities of daily living (ADL).

In various parts of the world, institutions and researchers are engaged in studies involving robots and exoskeletons for rehabilitation purposes. These teams are composed of professionals from different fields, such as engineering, neurology, and occupational therapy, who are dedicated to verifying, testing, developing prototypes, and comparing both the devices themselves and the methodologies used (Marcelino et al., 2021).

It is worth emphasizing that occupational therapy plays a role from the earliest stages of device development, collaborating with teams and testing methodologies or more effective ways of using robotics and exoskeletons (Azcona et al., 2023).

An exoskeleton is an external structure attached to a limb, designed to enhance performance or substitute the function of a muscle in cases of impaired movement (Ferreira, 2018). According to this author, the primary purpose of exoskeletons can be divided into two categories: strength augmentation and rehabilitation. The application of actively controlled external force is required, where the equipment can perform the movement regardless of the condition of the affected limb. There are several types of exoskeleton layouts according to energy source, mechanical actuation, and force transmission devices between the machine and the body. The main types include electromechanical, pneumatic, hydraulic, and electromyographic systems (Bos, 2016; Gull et al., 2020; Noronha & Accoto, 2021).

Given these features and benefits, the exoskeleton was selected as the device to be used in a motor learning program. Therefore, to test a hand exoskeleton with specific characteristics, the aim was to find a model capable of meeting the demand for high speed and high torque to reproduce movements similar to those of a healthy hand in the impaired one. The goal was also to develop a model with simpler construction, lower cost, greater comfort, and improved ergonomics: an electromechanical exoskeleton powered by a battery, with mechanical traction via pulley and traction wire.

General objective

To describe the development and initial test results of a hand exoskeleton for individuals with mild hemiparesis, highlighting the contributions of occupational therapy in the construction process conducted by a multidisciplinary team.

Specific objectives

To describe the construction process of the hand exoskeleton for individuals with mild hemiparesis, highlighting the contributions of occupational therapy to its development.

To present the results of the exoskeleton tests and the preliminary evidence resulting from its use.

Method

Ethical aspects

This study was approved by the Research Ethics Committee (CEP) and the National Research Ethics Commission for Human Subjects (CONEP), in compliance with all their recommendations. The data were stored on devices belonging to the researcher, such as flash drives and external hard drives, and will be kept for five (5) years. After this period, the data will be deleted.

There was no discrimination in the selection of individuals for this study, and participants' privacy was ensured, in accordance with the General Data Protection Law (LGPD) – Law No. 13.709/2018.

Research stages

This study is organized in two stages. The first presents the context and the theoretical-methodological foundations adopted for the product's development, highlighting the construction sequence and occupational therapy actions, thus comprising a theoretical-practical stage. In addition to the description of the construction process, the first stage includes a pre-experimental study (Magalhães & Murta, 2003), which verified the feasibility of using a hand exoskeleton in a motor learning program before and after the intervention (pre- and post-intervention), with a quantitative-qualitative analysis of the results. Preliminary evidence from tests of the prototype with five participants is presented. The second stage highlights the contributions of occupational therapy based on the Design Thinking method adopted in the development of the exoskeleton.

Participant recruitment procedures

The Modified Ashworth Scale (Bohannon & Smith, 1987) and the Montreal Cognitive Assessment (MOCA) (Nasreddine et al., 2005) were used to recruit the study participants. These assessments were conducted by a faculty researcher who acted independently to reduce potential research bias.

Inclusion and exclusion criteria

The study included post-stroke patients with mild to moderate hemiparesis, as defined by grades 0 to 2 on the Modified Ashworth Scale, with trunk control, active shoulder and elbow movement, and preserved cognitive components (Montreal Cognitive Assessment, MOCA ≥22 points), aged 18 or older, with one participant identifying as male and another as female. Excluded from the study were post-stroke patients with severe hemiparesis, limited trunk balance and active movement of the shoulder and elbow, those with cognitive impairment (MOCA ≤22 points), and those participating in other rehabilitation programs involving stimulation of the upper limbs (UL).

Participants

Five individuals participated in the study: two healthy individuals took part in preliminary tests, the results of which contributed to improvements in the exoskeleton. Subsequently, a pilot phase was conducted with one female participant (pilot study participant - PP), D., aged 37, with a high school education and right upper limb hemiparesis. She was not undergoing other rehabilitation treatment during the research, and the results of her participation supported procedural adjustments and improvements in the exoskeleton. Based on the results from the pilot phase, the program with the exoskeleton was applied to two other participants with mild hemiparesis.

Participant 1 (P1) is a 61-year-old male mechanic, divorced, with an 8th-grade education. He had experienced an ischemic stroke 11 months earlier, with sequelae in the left side of his body. He is right-handed, received no intervention at the time of the study, and had no language impairments. He scored 27 out of 30 on the MOCA-B, indicating normal cognitive function. On the Modified Ashworth Scale, he had grade zero tone in the affected upper limb. Participant 2 (P2) is a 66-year-old widowed male, retired driver, with a 9th-grade education. He had suffered a stroke that resulted in motor sequelae in the upper limb. He was not receiving intervention at the time of the study. He scored 22 out of 30 on the MOCA-B, indicating normal cognition. He had grade 1 tone in the affected limb according to the Modified Ashworth Scale.

According to the inclusion criteria, three post-stroke individuals with hemiparesis participated in this study stage: one female (aged 37, pilot phase) and two males (aged 61 and 66).

Data collection procedures

The following instruments were used to collect quantitative data pre- and post-intervention: the Motor Activity Log (MAL) (Taub et al., 1993) and the Disabilities of the Arm, Shoulder and Hand (DASH) (Orfale, 2003). For qualitative data collection, a semi-structured interview was conducted after exoskeleton use, along with the researcher's notes describing the sessions, the activities performed, observations, and participants' comments.

Data analysis

Quantitative data were analyzed based on the scores from the applied instruments. The MAL was used to assess the function and spontaneous use of the hemiparetic upper limb, whereas DASH was applied to evaluate upper limb function and symptoms.

The MAL provided both quantitative and qualitative scores for the use of the affected upper limb. DASH yielded a percentage score related to upper limb function and symptoms.

Qualitative data (interviews and researcher's notes) were analyzed using content analysis. According to Minayo (2000), this method involves stages that include pre-analysis, material exploration, and treatment/interpretation of the results obtained, allowing for the content of the messages to be clarified, systematized, and expressed.

In the first stage, the material was organized and systematized in tables with dates and notes. The software ATLAS.ti® was used to generate the initial analysis codes, aiming to statistically process the data, code the database, and systematize the content analysis stages (Silva Junior & Leão, 2018). After code generation, categories were analyzed and thematic units were selected based on recurring codes.

Location

Bench tests were conducted in university laboratories, with the participation of volunteers (robotics specialists and a mechanical technician), who contributed in distinct and complementary ways at different test stages. Recruitment was carried out at a university hospital. Other tests were performed in a treatment room of an ambulatory teaching unit, involving both healthy individuals and individuals with hemiparesis, and all procedures were recorded on video.

Results

The results are organized as follows: first, the development process of the hand exoskeleton is described, along with reflections on the actions and contributions of occupational therapy in this process. Next, the testing of the exoskeleton is presented. Finally, the initial evidence resulting from its use by individuals with mild hemiparesis is provided.

Description of the Hand Exoskeleton Development Process

Initial definitions

To establish the foundation for the hand exoskeleton development process, a literature review was conducted, revealing models that influenced specific design choices in the present project. As an example of electromechanical actuation, the exoskeleton developed by Nazari et al. (2021) stands out, as these authors address the complexity of thumb movement. Another relevant model that inspired this study was the exoskeleton by Serbest & Eldogan (2021), which employs a force transmission system using traction wires and operates with only one linear actuator.

The structure of the exoskeleton developed by the authors of this study was designed with adaptability as a key goal, with its design being continuously adjusted to fit different hand sizes. To achieve this, a pulley winding control system was implemented using buttons, enabling customization of the users' maximum finger extension and flexion positions.

To reduce the equipment's weight and dimensions, while optimizing spatial arrangement and torque, a set of servo motors with pulleys pulling nylon wires was used. These components were placed on the forearm section of the exoskeleton, ensuring mobility and applicability to various types of rehabilitation, including programs based on the Mirror Neuron System.

Another important definition was informed by the motor and sensory limitations experienced by individuals with hemiparesis. It was considered that developing an exoskeleton grounded in Mirror Neuron System-based training and functional rehabilitation (Mao et al., 2020) could enhance its usability.

Adopting Design Thinking to address the challenge

The Design Thinking method was adopted to address the challenge of creating the exoskeleton based on the selected features. This problem-solving approach incorporates creativity tools and concepts from various disciplines. Centered on the user, the method aims to foster innovation through phases of inspiration, ideation, and implementation, which do not occur linearly (Bukowitz, 2013; Bonini & Sbragia, 2011; Macedo et al., 2015).

During the inspiration phase, a multidisciplinary team was formed to identify problems and discuss the characteristics of the target population—individuals with mild hemiparesis. Following Bonini and Sbragia's (2011) framework, brainstorming sessions were held, and the results were converted into prototypes after extensive debate.

The adopted Design Thinking approach facilitated the co-creation process by a group composed of occupational therapists, computer scientists, mechanical engineers, and undergraduate and graduate students. All team members were involved and motivated to develop a device based on a basic exoskeleton design. The goal was to enhance hand engagement while ensuring both the structural foundation of the prototype and the necessary freedom of movement for user rehabilitation.

To this end, a thermoplastic base—a material commonly used in upper limb orthoses— was designed and molded respecting the palmar creases and metacarpophalangeal joints of an adult hand.

Drawing on occupational therapy expertise in the hand exoskeleton development process

Specific knowledge from the field of occupational therapy played a key role in this process, including the analysis of material properties for exoskeleton construction, the physiological, anatomical, and kinesiological aspects of the individual—particularly regarding the upper limb—as well as considerations related to comfort and ergonomics.

The exoskeleton was initially conceived as a motion-copying orthosis, enabling a person diagnosed with stroke and with limited movement, such as hemiparesis, to stimulate movement using the unaffected upper limb. Based on this layout, the first virtual prototype was designed to ensure the desired movement freedom while accommodating the actuators, power source, and embedded computer.

Discussions were held regarding the design rationale for the exoskeleton, emphasizing the importance of anatomical alignment so that the proposed model would closely follow the anatomy and semiology of the hand and forearm. Team discussions incorporated shared knowledge from multiple disciplines regarding the design of finger rings, hand anatomy—with emphasis on the interdependent movements of the phalanges—and the pursuit of harmonious motion, achieved through the joint action of ligaments, pulleys, and tendons that form the osteofibrous tunnel and the extensor hood of the fingers. Accordingly, the design featured additively manufactured components affixed to the phalanges with Velcro or Neoprene®, connected by a nylon wire.

Throughout the prototype development, adjustments were made to accommodate anatomical limits and bony prominences, with particular attention to the metacarpal head and the radiocarpal joint. Two servo motors of different sizes were tested to minimize the forearm-mounted electromechanical base and assess traction force. The smaller servo motor (SG90) proved insufficient to overcome finger flexion in a healthy individual compared to the larger MG966R model, which was therefore retained.

The next research stages involved developing the circuits responsible for motion-copying between the unaffected and affected hands.

Still within the ideation phase, the first circuit was assembled to transmit data wirelessly from the healthy hand controlling the exoskeleton. The glove structure included the following components: Arduino® (microcontroller), XBee® (wireless data transmitter), Linear Flex Sensor (captures finger movement variation via deformation, generating electrical resistance variation), 56 kΩ resistor (circuit component), and jumpers.

The second circuit was assembled to receive wireless data and activate the hemiparetic hand fitted with the exoskeleton. This glove included: Arduino®, XBee®, MG966R® servo motor (more powerful model), and jumpers.

Programming was carried out so that the data captured by the glove sensors would be processed by the two Arduinos and sent to the servo motor, enabling finger extension or pause movements in one hand to be mirrored in the other.

With the advancement of another stage and the refinement of the exoskeleton prototype, it became possible to *wear* it and test its anatomical fit, range of motion, and comfort. During this testing, the device was secured using Neoprene Velcro Japan®[2], a material with one rubberized surface and the other resembling Velcro, which ensures both comfort and ease of adjustment to the body segment. This material was also used to line the parts of the exoskeleton that were in contact with the back of the hand and the posterior portion of the forearm.

Pressure points were observed in the proximal third of the forearm, the ulnar styloid process, the first web space, and the head of the second metacarpal. When the

[2] Neoprene is a type of synthetic rubber derived from petroleum, expanded under high pressure and temperature, and has been used for over 70 years. Velcro Japan fabric has characteristics similar to the female side of Velfix®, which is a hook-and-loop fastener that facilitates sewing (Inneo Neoprene Brasil, 2021).

traction mechanism of the second finger was activated (servo rotation and nylon wire tensioning via pulley), the prototype had to be switched off to prevent the traction from exceeding the anatomical extension limit of the finger—indicating the need to incorporate a safety system.

To reflect on the pressure points and identify the anatomical structures that should be protected from direct material contact, a drawing was made directly on the researchers' body segment using a ballpoint pen.

Additional needs were also identified, including resizing the support tray (which was too large), resolving friction between the nylon wire and the prototype material, and rounding all edges to avoid skin abrasion.

Regarding safety, two potential solutions were considered: the installation of an encoder[3] or a mechanical safety lock.

Tests were also conducted using the sensor glove and the exoskeleton to verify the response time between the finger extension movement performed by the segment wearing the glove and the replication of that movement by the segment fitted with the exoskeleton, as illustrated in the image sequence in Figure 1.

To address the response time delay, a functional test of the prototype was performed, involving adjustments to the programming, electrical connections, and calibration of the finger extension and flexion movements in the exoskeleton, using a device developed by the study team. These adjustments resolved the response time issue between the movement detected by the control glove and the action of the exoskeleton, and established limits for flexion and extension angles, providing greater safety and more accurate replication of movements between the gloves.

The participation of a volunteer in the tests for body fitting and verification of the exoskeleton's functionality is highlighted (Figure 2). Figure 3 presents all the parts and components of the final version of the exoskeleton, as delivered by the study team.

Hand Exoskeleton Testing

A) Testing with healthy individuals: exploring the exoskeleton through activities from the occupational therapy motor learning program

The first test involved using the exoskeleton to perform finger flexion and extension movements. The second test was based on activities from the program Motor Learning for Activation of the Mirror Neuron System for Participation in Occupations (AMANE-PO) (Paiva, 2024).

The activities consisted of picking up medium and large blocks and releasing them onto the table; removing tubes from a holder and reinserting them; picking up a cup from the table, bringing it to the mouth, and returning it to the table; picking up small and medium blocks, placing them on a box, and then returning them to the table; cutting dough using cutlery; and rolling out dough using a rolling pin.

[3] A rotary, or shaft, encoder is an electromechanical device that provides information on a motor's position, count, speed, and direction, and is connected to an application through a control device (Portescap, 2021).

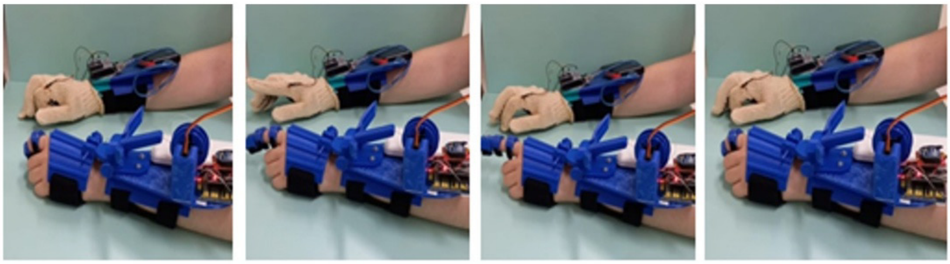

Figure 1. Sequence of the activation test with the sensor glove and the exoskeleton fitted to body segments. Tests were conducted using only the second finger of each hand (Source: Prepared by the authors).

Figure 2. Body fitting and functionality tests of the exoskeleton (Source: Prepared by the authors).

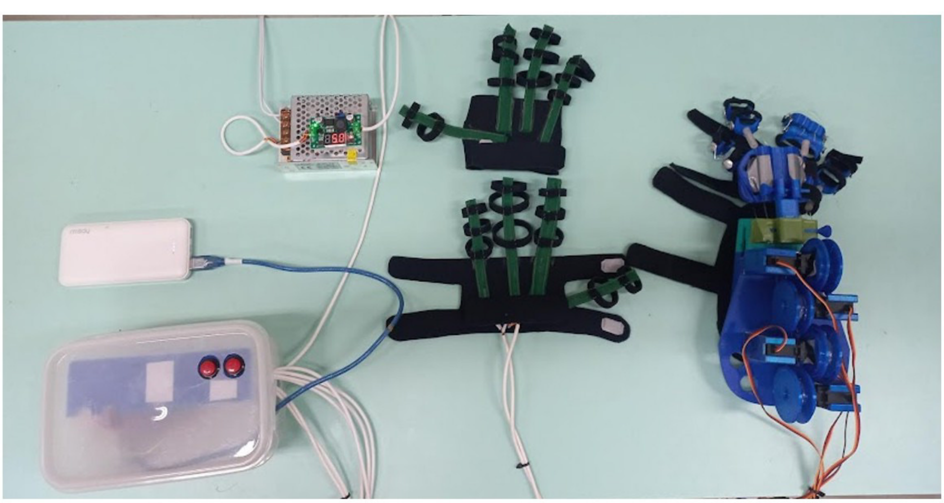

Figure 3. Parts and components of the final version of the exoskeleton, as delivered by the study team (Source: Prepared by the authors).

In the tests with the first user, initial perceptions indicated discomfort related to the device's weight and insufficient strength for full finger extension. During the second round of tests, the activities were performed without any notable difficulties.

With the second user, initial perceptions indicated discomfort due to the need for the exoskeleton to remain plugged into an outlet and the presence of many connecting wires. The user suggested adapting it to operate on battery power to make it portable. The need to reduce the exoskeleton's size was also highlighted, along with the importance of the user being able to visually track their movements and the synergy involved, both of which contribute to proprioception. In the second round of activity testing, users reported less difficulty related to the size of the exoskeleton.

B) Description of the pilot test of the exoskeleton with activities from the occupational therapy motor learning program with an individual with hemiparesis

In this stage, one participant meeting the study's inclusion criteria participated: D., a 37-year-old with right hemiparesis. Initially, a familiarization session was held, and questions were addressed. Testing began with the researcher instructing the participant to perform hand opening and closing movements. The participant reported that the device did not provide sufficient strength for full finger extension.

In the second phase, AMANE-PO activities were performed. Again, the participant noticed insufficient device strength, particularly when attempting to pick up large blocks and release small, medium, and large blocks onto the table.

To address the difficulty in achieving full finger extension, adjustments were made to the nylon wires and pulleys, and the 3D-printed component for the index finger was replaced with an orthosis. This modification improved the performance of that segment.

In the third round of testing, the researcher instructed the participant to place the open hands over the blocks and only then perform the grasping movement. Although greater extension of one of the fingers was observed, the participant was still unable to grasp the block with the affected hand.

Upon observing that the orthosis on the index finger provided better extension, all components of the exoskeleton were replaced with thermoplastic material. The new version was tested with a healthy volunteer.

As in the pilot test, the exoskeleton rings that attached to the fingers were made of thermoplastic and required individual adjustment for each participant. As a result, further modifications were made, including replacing the thermoplastic material with Orficast®, which is more flexible and creates less friction with the objects used during AMANE-PO sessions with the exoskeleton.

Initial Evidence of the Performance of two Individuals with Mild Hemiparesis Following the Use of the Exoskeleton

This section presents the results of the interventions with the exoskeleton in two participants in this study, referred to as participant 1 (P1) and participant 2 (P2). It is important to clarify that, because of differences in the side of the upper limb affected by hemiparesis (P1 on the left and P2 on the right), the exoskeleton had to be configured for each participant.

The configuration involved adjustments to the device, including switching out the activation gloves (right hand or left hand), repositioning the traction wires in the exoskeleton guides (index, middle, and ring fingers), and performing electronic calibration via buttons to adjust the wire length from the pulley to the rings to fit each participant's hand. Both participants completed sessions of the AMANE-PO program (Paiva, 2024).

After five testing sessions using the exoskeleton, both participants reported positive changes in the use of the affected limb and in the performance of ADL. The results obtained through the applied instruments are presented in Table 1.

Table 1. Results for participants 1 and 2 in the pre- and post-intervention stages, collected using the Motor Activity Log – Brazil (MAL) and Disabilities of the Arm, Shoulder and Hand (DASH).

Instrument	Participant 1		Participant 2	
	Pre-intervention	Post-intervention	Pre-intervention	Post-intervention
MAL	Quantitative: 3.36	Quantitative: 3.1	Quantitative: 1.6	Quantitative: 2.7
	Qualitative: 3.0	Qualitative: 3.6	Qualitative: 1.4	Qualitative: 2.4
DASH	43.7% (Moderate)	32.5% (Moderate)	45% (Moderate)	23.3% (Mild)
	Work: 37.5%	Work: 56.2% (Severe)	"Work" not scored.	"Work" not scored.

Participant 1: On the MAL instrument, a slight reduction was observed in the quantitative scale (from 3.36 to 3.1) and improvement in the qualitative scale (from 3.0 to 3.6) between the pre- and post-intervention assessments. On the DASH instrument, the participant remained within the moderate limitation range in the first section, with an improvement in overall score (from 43.7% to 32.5%). However, in the work-related section, the score worsened, shifting from moderate (37.5%) to severe (56.2%) due to a change in job duties.

Participant 2: Demonstrated significant improvements on MAL, both in the quantitative (from 1.6 to 2.7) and qualitative (from 1.4 to 2.4) scales, indicating greater functionality and use of the affected upper limb. On DASH, the score improved from moderate (45%) to mild (23.3%) limitation. The work-related section was not applied, as this participant was not engaged in employment.

Next, Table 2 presents results based on the researcher's notes recorded during the exoskeleton use sessions with both participants, in the context of the AMANE-PO program activities. Table 3 shows the results of two semi-structured interviews conducted after the intervention. The data were analyzed using content analysis, and the corresponding categories and thematic units are presented in Table 2.

Table 2. Categories and thematic units generated from the researcher's notes during the interventions.

	Categories	Thematic units
I	Improvements in exoskeleton functionality	Performing new tests and making necessary modifications
II	Difficulties in performing tasks	Researcher interventions
III	Improvements in motor skills	Ability and ease in performing tasks

Source: Prepared by the authors – research data.

Regarding Category I – Improvements in exoskeleton functionality, under the thematic unit *Performing new tests and making necessary modifications*, it was noted that even with the orthoses fabricated from thermomoldable material, further adjustments were required. As recorded by the researcher: "When reaching for small, medium, large, and extra-large blocks, it was observed that the thermoplastic material was hindering object grasp. Therefore, the decision was made to remake the rings using Orficast®, which has a thinner profile and greater flexibility."

During testing, Participant 1 suggested separating the third and fourth fingers in the rings, as the fourth finger remained flexed. This adjustment—fabricating new rings to separate the fingers—facilitated task performance, even though the fourth finger remained flexed. This modification was perceived as positive: "The patient easily performed tasks such as inserting the tubes, picking up the cup, simulating drinking, and picking up and releasing the small blocks, using only the anti-slip aid." (Figure 4a and b).

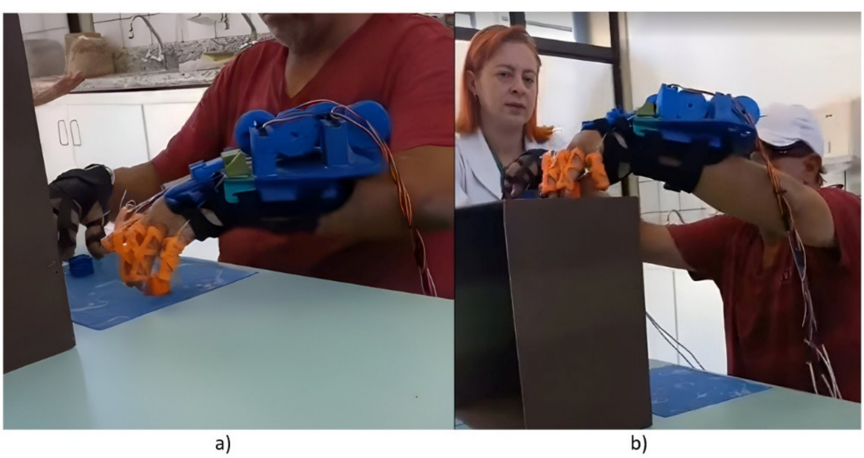

Figure 4. a) Participant picking up small blocks; b) participant releasing small blocks over the box. (Source: Prepared by the authors).

New adjustments were made to the Orficast® orthoses, proposed by the participant themself, to assess whether finger traction strength could be improved. The space where the wire connects the gear to the finger was reduced.

Tests were conducted with small balls, medium, large, and extra-large blocks. However, it was observed that the exoskeleton did not fully achieve proper finger extension, with insufficient force particularly in the third and fourth fingers, as well as in the thumb. By mutual agreement, the researcher and the participant decided to revert to the previous configuration.

Category II – *Difficulties in performing tasks Researcher interventions*: It was observed that Participant 1 did not require verbal interventions or physical assistance. Participant 2 required some support: "To assist with friction between the exoskeleton and the larger ball, rough Velcro strips were attached." "The participant required physical assistance to support the elbow and wrist when rolling out the dough with a rolling pin" (Figure 5). "Support was provided at the elbow and shoulder to help with forearm pronation when using a fork to pierce the modeling dough." "For the smaller balls, the participant was instructed to perform the grasp directly into the researcher's hands and, after successfully doing so, to release the balls into the researcher's hands as well, held slightly above (at the height of the box). This was necessary because the participant required support at the elbow and shoulder and assistance for grasping the object due to its small size."

Figure 5. Physical support provided by the researcher to Participant 2. (Source: Prepared by the authors).

In Category III – *Improvements in motor skills*, within the thematic unit *Ability and ease in performing tasks*, it was observed that as adjustments were made to the exoskeleton, motor skills, as well as the ability and ease of performing tasks, consequently improved during the activities.

As the final element of the qualitative analysis, the following presents the categories and thematic units resulting from the content analysis of the interviews conducted after the exoskeleton intervention with both study participants (Table 3).

Table 3. Categories and Thematic Units of the Interviews.

	Categories	Thematic units
I	Expectations and experiences of participating in the research	Changes in strength and movement
II	Changes in routine activities	Changes in how routine and work activities are performed

Source: Prepared by the authors – research data.

Regarding Category I – *Expectations and experiences of participating in the research*, within the thematic unit *Changes in strength and movement*, it was observed that Participant 2 noticed changes in these aspects, as reflected in the following comments: "It was good, it improved a lot, the strength came back" and "I can move more." Participant 1 did not mention aspects related to strength or movement. However, regarding Category II – *Changes in routine activities*, within the thematic unit *Changes in how routine and work activities are performed*, this participant reported that they began performing tasks more calmly and can now grasp small objects, such as a pencil and an eraser, and use a knife to cut food with the affected limb. In the same thematic unit, Participant 2 reported that they were previously unable to button their pants or put on their shoes but can now perform these tasks.

Based on the data analysis, it is understood that the development of a hand exoskeleton, combined with its use in activities within an occupational therapy program focused on motor learning, proved to be a promising pathway to promote participation in everyday occupations for individuals with mild hemiparesis.

Discussion

This study aimed to describe the development of a hand exoskeleton for individuals with mild hemiparesis, conducted by a multidisciplinary team. In this descriptive process, it sought to highlight the contributions of occupational therapy in the construction of the exoskeleton. Mashizume et al. (2021) state that the effectiveness of robotic therapy in the rehabilitation of individuals after stroke has already been demonstrated in several studies, and that occupational therapists should consider the use of robotics in their clinical practice. However, little is known about these professionals' experience with robotics in their practice settings. The data presented here highlight the contributions of occupational therapy from the inception of the hand exoskeleton through its use and evaluation of its potential. They also demonstrate its collaboration with multidisciplinary teams, testing methodologies and materials to enhance the device's usability for individuals with hemiparesis.

During the intervention process, a motor learning program was implemented for individuals with hemiparesis, considering their motivations and interests in performing movements— a factor believed to have contributed to the outcomes achieved. The literature underscores the importance of individuals' motivation and the meanings attributed to occupations. Buccelli et al. (2022) emphasize that engaging exercises positively impact motivation, enabling bodily movement, involving individuals in games, and promoting physical-social interactions. Occupational therapy research values the simulation of intentional occupations (such as activities of daily living and work) to foster reintegration of individuals into their routines, including previously performed social roles (Buccelli et al., 2022).

The participants' reports of positive changes, particularly in work and daily routine activities, indicate improvements. Araújo et al. (2022) state that occupational therapy focuses on occupations, aiming to improve individuals' functionality. Currently, the profession is entering the context of the digital revolution, where rehabilitation technologies (RT), such as robotics and virtual reality, are integrated into clinical practice. Thus, occupational therapists are beginning to consider robotics as a complement to other therapies, contributing to improvements in body function and fostering patients' desire for independence (Mashizume et al., 2021).

Cruz et al. (2023) suggest that occupational engagement is a highly complex concept, encompassing various levels of the Model of Human Occupation (MOHO). This complexity is reflected within the concept of occupational participation, which involves a subjective dimension of performance.

The MOHO, the model adopted in this study, proved suitable, as it considers aspects related to occupational participation, including elements of the person (such as volition, occupational patterns, and skills) and the environment. It can thus be concluded that the contribution of occupational therapy in developing the hand exoskeleton considered participant-related information and life factors, especially those linked to home and work environments.

One of this study's objectives was to describe the contributions of occupational therapy in constructing a hand exoskeleton, considering the numerous technological advances that have enabled the use of mechanical systems in performing activities. Through collaborative work with a multidisciplinary team—composed of professionals from the fields of mechanical engineering, computer science, and robotics—it was possible to identify specific contributions from the field of occupational therapy.

It is understood that these contributions occurred, in this study, at four stages: inception (ideation), development, testing, and application. It is noteworthy that the work dynamic involved occupational therapy participation from the initial idea through the analysis of participants' needs, through information exchange with team members and discussions in meetings throughout the entire process, characterized by the following actions:

1. Identifying the needs presented by the target population, determining the real necessity for a hand exoskeleton to enhance occupational therapy processes;
2. Ideating the concept of an orthosis activated by contralateral movement, engaging the Mirror Neuron System;
3. Considering ergonomic and safety aspects arising from anatomical analyses, body fit tests, pressure points, and aesthetics;
4. Defining and refining the materials used, considering criteria such as flexibility, hardness, texture, and weight, focusing on anatomical comfort and freedom of movement;
5. Participating in problem-solving to enable the use of the exoskeleton in the motor learning program;
6. Participating in bench tests, making adjustments to improve device performance;
7. Conducting tests with healthy individuals and the pilot participant, taking into account their perceptions and needs, and analyzing performance in activities;
8. Carrying out the first application with participants with mild hemiparesis, integrating the motor learning program with the use of the exoskeleton;
9. Evaluating the strengths of using the exoskeleton in motor learning program activities, as well as identifying areas requiring improvement for future applications.

The results indicate that during the testing sessions, several adjustments were made to the exoskeleton for both participants, who actively collaborated by providing feedback to improve the device. The changes primarily concerned friction between the exoskeleton and the materials of the objects used. In addition, separation of the fingers was requested to allow greater freedom of movement.

Overall, both participants demonstrated motivation to use the exoskeleton and to perform the activities of the AMANE-PO program. It is important to note this positive motivation, observed by the researcher and expressed verbally by the participants during their experience with the exoskeleton. Participant 2 stated: "I could really feel it pulling," while Participant 1, as recorded in the researcher's notes, "(...) seemed very comfortable and enthusiastic during the tests, even mentioned that he was enjoying the process. Furthermore, at times, he reiterated that he did not have sensation in some fingers of the affected hand, but he could feel the exoskeleton pulling and opening his hand." Both reports reflect the participants' satisfaction with the return of movement in the distal extremity.

Mandeljc et al. (2022) explain that individuals affected by stroke often experience spasticity in the upper limb and must also contend with the fact that recovery of movement in the distal joints of the arm—compared to proximal joints—typically occurs later. Even when motor skills recover in the proximal joints, functional delays persist in the wrist and fingers, which leads to greater limitations in activities of daily living (ADL). To perform meaningful activities, these individuals require coordinated action of the entire upper limb, specifically the wrist and hand (Mandeljc et al., 2022). According to these authors, an appropriate rehabilitation device can support recovery of wrist and finger movements, provided that it can facilitate flexion and extension movements, allow adjustments in levels of assistance, motivate the patient, and provide visual feedback (Mandeljc et al., 2022).

Although there is extensive evidence attesting to the functionality and robustness of assisted robotic rehabilitation in therapeutic processes aimed at motor recovery, evidence regarding variables that may predict better performance remains limited (Pignolo et al., 2021). Although the use of the hand exoskeleton combined with the AMANE-PO program was limited to five sessions per participant, it was possible to observe that both participants showed improvements in the spontaneous use of the affected limb, as well as in upper limb function and symptoms during the performance of ADL. It is noteworthy that, in the DASH instrument, one participant progressed from a moderate to a mild classification.

However, Participant 1, despite presenting a milder impairment compared to Participant 2, demonstrated a quantitative decline in the spontaneous use of the affected limb and in the work section (progressing from moderate to severe), as a result of having changed job roles due to the difficulties experienced in performing tasks required in their occupation as an automotive mechanic.

Considering the findings of this study, along with the evidence identified in the literature that supports the discussion presented here, it is possible to state that technology has driven significant changes in the field of rehabilitation, with occupational therapists playing a leading role in this movement and contributing meaningfully to individuals' functionality and participation in everyday occupations.

The use of robots and exoskeletons as tools in rehabilitation has garnered growing interest in occupational therapy (Zilli et al., 2014). This assistive technology has been explored primarily in neuromotor rehabilitation contexts, such as spinal cord injury, stroke, and degenerative conditions (Monzeli et al., 2016; Mendes et al., 2016; Cruz & Zanona, 2022).

While there is consensus regarding the potential of these devices to promote functional gains—such as improved gait and increased range of motion—occupational therapists also point to significant challenges, including high cost, the need for specialized training, and the need to tailor the technology to the specific demands of each patient (Azcona et al., 2023).

Finally, the limitations of the results presented here must be acknowledged. The sample was small, the number of sessions was limited—the initial plan included 12 sessions—and the assessments were based on only two instruments.

For future studies, it is recommended that the motor learning program combined with the use of the hand exoskeleton be applied to a larger sample, which would make it possible to adopt quasi-experimental designs.

Final Considerations

Conducting this study required theoretical research, as well as the dedication and effort of a team composed of professionals from different fields of knowledge, including undergraduate students, master's and doctoral students, technicians, and volunteers. It is believed that this work provided specific learning about the development and use of a hand exoskeleton, as well as an opportunity for teamwork, fostering dialogical relationships in developing solutions to the problems encountered and overcoming barriers throughout the research process from an interdisciplinary perspective.

Through the experience reported here, the actions and contributions of occupational therapy in the collective construction of solutions to problems are made explicit, from the inception of a hand exoskeleton developed for individuals with mild hemiparesis.

The next steps of the research include finalizing the development of the exoskeleton, which is already in the process of intellectual property protection, with a patent application submitted to the university's innovation agency.

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Author's Contributions

Gisele Paiva was responsible for conception of the proposal, execution of the research, and writing of the manuscript. Claudia Maria Simões Martinez was responsible for supervision and guidance of the research, and revision of the manuscript. Jaciane Borges Lopes Cerqueira was responsible for data collection and analysis, and writing of the manuscript. Sérgio Henrique Flório was responsible for execution of the research and writing of the manuscript. Rafael Vidal Aroca was responsible for co-supervision of the research and revision of the manuscript. All authors have approved the final version of this article.

Data Availability

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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