ORIGINAL ARTICLE

Design, development, and optimization of "Tomy", a social robot designed to complement psychological care for children hospitalized with hematologic malignancies

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ABSTRACT

Objective: To describe the design, manufacturing, electronic and digital integration, and functional optimization of "Tomy", a social robot designed as a complementary tool to be used alongside routine psychological care for children aged 6–12 years hospitalized with hematologic malignancies.

Methods: A technological development and early technical evaluation study was conducted using a user-centered design approach. Individual surveys and an exploratory group feedback activity were conducted with hospitalized pediatric patients to identify their preferences and define the robot's appearance, modes of interaction, and functional requirements. A participatory session was also conducted with psychologists from the Hematology Service to align the robot's intended functionalities with the objectives of routine psychological sessions. The development process comprised three iterations: an initial proof of concept, an intermediate prototype, and a final functional prototype, all designed using three-dimensional digital modeling and manufactured through fused deposition modeling 3D printing with polylactic acid filament. After the electronic and digital components were integrated into the final functional prototype, functional testing and optimization were performed. Clinical outcomes were not evaluated.

Results: In the initial exploratory survey of three patients, two preferred an animal morphology over a humanoid appearance. The information obtained was used to develop a proof-of-concept prototype with a canine morphology. This model was subsequently presented during an exploratory group feedback activity with three patients, whose comments informed adjustments to the appearance and intended modes of interaction, resulting in an intermediate prototype. In the aesthetic validation survey, nine of the 10 patients indicated that they liked the robot's shape and considered its appearance friendly; all stated that they would like to have such a robot during their hospitalization. The psychologists' participation helped identify the objectives and activities of routine psychological care and define functionalities intended for future integration into these sessions. The iterative process resulted in a final functional prototype with a canine morphology that was operated by a psychologist through a web interface with predefined content and commands. The robot incorporated a facial display with four preprogrammed expressions (tiredness, happiness, anger, and sadness), movements of the head, tail, and hind legs, LED lights to indicate specific body parts, and accessories (stethoscope, flower, hat, and face mask) designed to complement the content intended for the psychological sessions through visual and play-based elements.

Conclusion: "Tomy" is a functional social robot prototype with canine morphology, designed with the participation of hospitalized children and psychologists, and conceived as a complementary tool to be used alongside routine psychological care for children hospitalized with hematologic malignancies. Its clinical implementation and effects on emotional outcomes were not evaluated. Future phases should assess its safety, feasibility, acceptability, usability, integration into psychological sessions, and added value compared with simpler alternatives, as well as its potential clinical effects and its ability to facilitate the structured delivery of content during psychological care.

Keywords: Robotics; Biomedical Technology; Child, Hospitalized; Hematologic Neoplasms; Psycho-Oncology (Source: MeSH)

Cite as:
Plasencia Ramos O, Figueroa Chávez AM, Puruguay León SJ, Gálvez-Arévalo RA, Caballa S, Mafaldo Rengifo AJ, Jiménez Montes MP, Acosta Huayama RM. Design, development, and optimization of "Tomy", a social robot designed to complement psychological care for children hospitalized with hematologic malignancies. Investig Innov Clin Quir Pediatr. 2026;4(2):39-50.
doi: 10.59594/iicqp.2026.v4n2.178

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Received : 06/24/2026
Accepted : 08/11/2026
Published : 08/28/2026

Diseño, desarrollo y optimización de "Tomy", un robot social concebido para acompañar la atención psicológica de niños hospitalizados por cánceres hematológicos

RESUMEN

Objetivo: Describir el proceso de diseño, manufactura, integración electrónica y digital, así como la optimización funcional de "Tomy", un robot social concebido como herramienta complementaria para acompañar la atención psicológica habitual de niños de 6–12 años hospitalizados por cánceres hematológicos.

Métodos: Se realizó un estudio de desarrollo tecnológico y de evaluación técnica temprana con un enfoque de diseño centrado en los usuarios. Se aplicaron encuestas individuales y se realizó una actividad grupal exploratoria de retroalimentación con pacientes pediátricos hospitalizados para identificar sus preferencias y definir los requerimientos de apariencia, interacción y funcionalidad del robot. Asimismo, se realizó una sesión participativa con psicólogos del Servicio de Hematología para alinear las funcionalidades previstas del robot con los objetivos de las sesiones psicológicas habituales. El desarrollo comprendió tres iteraciones: una prueba de concepto inicial, un prototipo intermedio y un prototipo funcional final, todas diseñadas mediante modelado digital tridimensional y fabricadas mediante impresión 3D con tecnología de deposición fundida, utilizando filamento de ácido poliláctico. Una vez completada la integración de los componentes electrónicos y digitales en el prototipo funcional final, se realizaron pruebas de funcionamiento y de optimización. No se evaluaron desenlaces clínicos.

Resultados: En la encuesta exploratoria inicial, aplicada a tres pacientes, dos prefirieron una morfología animal frente a una morfología humanoide. La información obtenida se utilizó para desarrollar una prueba de concepto con morfología canina. Posteriormente, este modelo fue presentado en una actividad grupal exploratoria de retroalimentación con tres pacientes, cuyos comentarios permitieron realizar ajustes en la apariencia y en los modos previstos de interacción para obtener un prototipo intermedio. En la encuesta de validación estética, nueve de los 10 pacientes encuestados indicaron que les gustaba la forma del robot y que este tenía una apariencia amigable; todos manifestaron que les gustaría disponer de uno durante su hospitalización. La participación de los psicólogos permitió identificar los objetivos y las actividades de la atención psicológica habitual y definir funcionalidades concebidas para su futura integración en dichas sesiones. Como resultado del proceso iterativo, se obtuvo un prototipo funcional final con morfología canina, operado por un psicólogo mediante una interfaz web con contenidos y comandos predeterminados. El robot incorporó una pantalla facial con cuatro expresiones preprogramadas (cansancio, alegría, enojo y tristeza), movimientos de la cabeza, la cola y las patas traseras, luces LED para señalar partes específicas del cuerpo y accesorios (estetoscopio, flor, sombrero y mascarilla) para complementar visualmente y lúdicamente los contenidos previstos para las sesiones psicológicas.

Conclusión: "Tomy" constituye un prototipo funcional de robot social con morfología canina, diseñado con la participación de niños hospitalizados y psicólogos, y concebido como herramienta complementaria para acompañar la atención psicológica habitual de niños hospitalizados por cánceres hematológicos. No se evaluaron ni su implementación clínica ni sus efectos sobre los desenlaces emocionales. Futuras fases deberán evaluar su seguridad, factibilidad, aceptabilidad, usabilidad, integración en las sesiones psicológicas y el valor añadido frente a alternativas más simples, así como sus posibles efectos clínicos y su potencial para facilitar la presentación estructurada de contenidos durante la atención psicológica.

Palabras clave: Robótica; Tecnología Biomédica; Niño Hospitalizado; Neoplasias Hematológicas; Psicooncología (Fuente: DeCS)

INTRODUCTION

Hematologic malignancies, such as leukemias and lymphomas, are among the most common cancers in children (1). The hospital environment poses a significant challenge for pediatric patients, who may experience a substantial emotional burden during the course of their disease and treatment. In children and adolescents with cancer, a systematic review and meta-analysis reported pooled prevalences of anxiety, depression, and post-traumatic stress disorder of 13.92%, 20.43%, and 20.90%, respectively, highlighting the need to consider mental health as part of comprehensive pediatric oncology care (2). More specifically, fear and emotional distress have been described as part of the hospitalization experience among children and adolescents hospitalized with acute lymphoblastic leukemia, particularly in relation to pain and the anticipation of invasive needle procedures (3).

Given this emotional burden, psychosocial care is recognized as an essential component of comprehensive pediatric oncology care. International standards recommend that children with cancer and their families receive systematic psychosocial assessment, psychoeducation, emotional support throughout the course of the disease, specialized mental health care when needed, and strategies for preparation or support before invasive procedures (4). In Latin America and the Caribbean, these standards have been adapted to promote their implementation in pediatric cancer centers, taking into account the needs of patients, their families, and healthcare teams (5). However, in resource-limited settings, the availability of professionals specialized in pediatric psycho-oncology may be insufficient to provide continuous support to all hospitalized patients. This situation, together with the need for structured resources tailored to the pediatric population, supports the exploration of complementary technological tools to support psychological care under professional guidance.

In this context, socially assistive robots (SARs) have emerged as innovative tools in pediatric hospital settings. A recent systematic review and meta-analysis suggest that SARs may have more favorable and consistent effects on pain management in hospitalized children, although the evidence regarding emotional outcomes, such as anxiety, fear, and distress, remains heterogeneous and inconclusive (6). Consistent with these findings, a previous systematic review of negative emotions in children in clinical settings found promising results for reducing anxiety and distress but emphasized that the evidence remains at an early stage and that higher-quality studies are needed (7). Another systematic review of social robot interventions in child healthcare reported favorable results for acceptability, feasibility, engagement, achievement of therapeutic or educational goals, pain reduction, and some mental health outcomes, while also noting that many studies were small, short-duration, and required more rigorous designs (8). Overall, these findings support the exploration of SARs as complementary tools in certain pediatric clinical settings, provided that their implementation accounts for the contextual, technical, ethical, and sustainability considerations of the hospital environment.

The main challenges associated with implementing SARs in hospital settings include acquisition and maintenance costs, the need to train healthcare personnel, and adapting these devices to the clinical, operational, and biosafety conditions of such environments. Humanoid robots have been estimated to cost up to approximately US$35,000, whereas pet-like robots cost approximately US$3,000, which may limit their adoption in resource-limited settings such as Peru (9). As a regional precedent, the local development of a low-cost social robot prototype designed to provide emotional support to children hospitalized with burns has been described, with manufacturing and electromechanical component costs of approximately US$350 (10). These precedents support the relevance of exploring locally developed technological solutions adapted to the hospital context.

Based on this background, "Tomy" was proposed as a social robot designed as a complementary tool to be used alongside routine psychological care for children hospitalized with hematologic malignancies at a national pediatric referral center in Lima, Peru. This study aimed to describe the design, manufacturing, electronic and digital integration, and functional optimization of "Tomy".

METHODS

Study design

A technological development and early technical evaluation study was conducted using a user-centered design approach, with a scope consistent with the preclinical stage, or stage 0, of the IDEAL-D framework (11). The study focused on the design, manufacturing, electronic and digital integration, and functional optimization of a SAR named "Tomy", designed as a complementary tool to be used alongside routine psychological care for pediatric patients aged 6–12 years hospitalized with hematologic malignancies at the Instituto Nacional de Salud del Niño San Borja (INSN-SB).

For these patients, psychologists in the Hematology Service routinely use an internal psychological intervention framework organized into seven structured sessions addressing key topics such as the therapeutic relationship, exploration of the hospital environment, self-image, emotional regulation, treatment adherence, empathy, emotional expression, and positive coping resources, within a care approach centered on the hospitalized child.

The first session involves establishing the initial therapeutic relationship (rapport); the second, exploring the environment; the third, strengthening a positive self-image; the fourth, autonomy and relaxation; the fifth, treatment adherence; the sixth, empathy and reflection; and the seventh, positive coping resources. All sessions last approximately 30 minutes and are conducted individually in patient rooms within the inpatient area of the Hematology Service at the INSN-SB.

"Tomy" was designed to be incorporated as a complementary tool from the first session and to be used alongside all seven sessions. Its use was planned under the guidance of the psychologist, who would introduce and operate the robot and select the content and modes of interaction according to the objectives of each session and the patient's needs. This framework guided the definition of the robot's content, functionalities, and interaction modes, as described in the following section.

User-centered design process and requirements definition

User participation took place in three stages during the design and optimization of the robot: an exploratory survey, an exploratory group feedback activity, and an aesthetic validation survey. These activities involved pediatric patients aged 6–12 years with a hematologic diagnosis who were hospitalized in the Hematology Service. Participants differed across stages, with no overlap between groups.

During the robot conceptualization stage, an exploratory survey was administered to three patients. The structured instrument consisted of 12 closed-ended questions: 11 single-response questions and one multiple-selection question. The questions explored preferences related to size, color, shape, eye type, the presence of legs or wheels, the inclusion of a screen and voice, voice type, preference for straight or angular versus rounded shapes, animal or human appearance, canine or feline morphology, and expected robot functionalities (Supplementary Table 1). Responses were tabulated using absolute frequencies and percentages; for the multiple-selection question, each selected option was counted independently.

Based on the information obtained at this stage, an initial proof of concept was developed using three-dimensional (3D) digital modeling and additive manufacturing with polylactic acid (PLA) filament.

This first model was subsequently presented to three other patients during an exploratory group feedback activity to gather their opinions and guide adjustments to the robot's appearance and intended modes of interaction. Comments were recorded at the group level and descriptively organized according to the aspects of the prototype they referred to; individual responses were not recorded, and opinions were not quantified by participant.

After incorporating the adjustments identified during this phase, an aesthetic validation survey was administered to 10 patients. The structured instrument included nine questions: three closed-ended single-response questions, four closed-ended multiple-selection questions, one semi-open-ended question, and one open-ended question. The open-ended question ("Why do you like or dislike it?") explored the reasons underlying participants' assessment of the robot's shape. The semi-open-ended question ("Would you prefer another breed or color?") included a dichotomous response and, when the response was affirmative, a field in which participants could specify their preferred breed or color. The remaining questions assessed acceptance of the robot's shape, color, and appearance; accessories; perceived friendliness; interest in having the robot available during hospitalization; expected activities; and desired interaction time (Supplementary Table 2). For the multiple-selection question on color and appearance preferences, each participant was asked to select two options; no specific number of options was established for the other multiple-selection questions. Responses to the closed-ended questions and the closed component of the semi-open-ended question were tabulated using absolute frequencies and percentages. For multiple-selection questions, each selected option was counted independently. Responses to the open-ended question and the open component of the semi-open-ended question were descriptively organized according to the aspects assessed.

Finally, a participatory session was conducted with three psychologists from the Hematology Service at the healthcare institution, who had approximately 11 years of experience in psycho-oncology. The session aimed to gather their perceptions of the functionalities to be incorporated into the final prototype and to align these functionalities with the objectives and activities of routine psychological care.

Conceptual and functional design of the prototype

The information obtained from the exploratory survey, the exploratory group feedback activity, and the aesthetic validation survey with hospitalized pediatric patients, along with input from psychologists from the Hematology Service, was integrated through a descriptive synthesis to define the conceptual and functional design requirements of "Tomy." No decision matrix, formal scoring, or weighting system was used.

For the conceptual design, patient preferences related to the robot's overall morphology, appearance, facial display, voice, posture, movements, and accessories were considered. These aspects guided the three-dimensional modeling and modifications made during successive prototype iterations.

For the functional design, the activities and modes of interaction suggested by the patients were compared with the objectives and activities of routine psychological care described by the psychologists. Based on this process, requirements were established for the delivery of verbal responses and other predefined audio content, the display of facial expressions through an integrated screen, the execution of simple body movements, and visual signaling using light-emitting diodes (LEDs). These functionalities were designed for future integration into psychoeducation, communication, and participation activities planned for routine psychological sessions.

It was also established that the prototype would be operated by a psychologist via a web interface, from which predefined content and commands would be selected based on the objectives of each session. "Tomy" was designed as a complementary tool to be used alongside routine psychological care, without replacing the professional or the therapeutic relationship with the patient. The clinical utility of the defined functionalities was not evaluated at this stage.

Manufacturing of the physical structure

The physical structure of the "Tomy" robot was developed from a 3D digital model created in Fusion 360. This software was used to define the geometry, dimensions, and main features of the parts comprising the prototype. The computer-aided design (CAD) model was organized into independent parts, with the main joints secured using M3 metric screws. Complementary shells, such as "Rear shell 1" and "Rear shell 2," were coupled using a form-fit joint with internal cylindrical metal elements 2 mm in diameter. An exploded view of the model and the main physical coupling solutions are presented in Supplementary Figure 1.

Manufacturing was performed using additive manufacturing via fused deposition modeling (FDM) 3D printing. This technique enabled the physical components of the prototype to be manufactured from the previously developed digital design and allowed progressive modifications during the iteration and user-validation process.

PLA filament was used for printing and was selected because of its availability, ease of printing, and suitability for developing functional prototypes. This process was used to manufacture both the robot's external structure and the complementary accessories designed to support the activities of the psychological sessions and promote interaction with pediatric patients.

The printed components were manufactured independently and subsequently inspected to verify dimensional compatibility, stability, and ease of assembly. After printing, the supports were removed, and the surfaces were finished to improve the prototype's physical appearance and facilitate the integration of its internal components.

Finally, the parts were assembled to form the robot's physical structure and its complementary accessories. During this stage, adjustments were made to connection points and coupling areas. The manufacturing process produced the prototype's physical structure, ready for electronic integration and functional testing.

Electronic components and hardware

The robot's central processing system used a Raspberry Pi microcomputer with 4 GB of RAM to manage the inputs and outputs of the physical peripherals. The mechanical actuation system comprised five 28BYJ-48 stepper motors with an operating voltage of 5 V, nominal torque of 34.3 mN·m, reduction ratio of 64:1, and a reported maximum operating noise level of 35 dB.

These motors enabled movements of the head and hind legs. An SG90 servo motor was also incorporated to enable articulated tail movement. For visual interaction, a Nextion touchscreen (74.4 mm × 42.9 mm × 4.6 mm) was integrated and used exclusively to display facial expressions and images. The touch function had no operational role and was not used by either the patients or the professional.

The auditory interaction system included a detachable microphone that was not operational in the prototype described. Audio output was provided through a Coolbox Teraware speaker system with a total power output of 6 W, distributed across two speakers, and volume adjustable via hardware and software controls. The system was positioned in the abdominal region, behind a series of openings in the shell designed to allow sound to exit. Stories, responses, and predefined sounds were played through this component. The manufacturer did not specify the maximum sound pressure level in decibels.

The design also incorporated five blue LEDs positioned to indicate specific parts of the robot's body during psychoeducational activities. Power was supplied by a rechargeable lithium-ion battery pack comprising 12 ZERNE 18650 cells rated at 3.7 V, with $LiNiMnCoO_2$ chemistry, arranged in a 3S4P configuration. The pack reached 12.6 V at full charge and had an estimated effective capacity of 12 Ah. For monitoring and protection, a 3S 25-A battery management system (BMS) was incorporated, providing protection against overcharge, overdischarge, overcurrent, and short circuit, as well as monitoring of the three series-connected groups. According to the manufacturer, the cells are certified under UL 1642, IEC 62133, and RoHS. The system was controlled using a physical on/off switch.

Battery life was estimated theoretically from the nominal voltages and maximum currents reported in the component datasheets. The maximum power of each component was calculated, and the individual power values were then summed to estimate the total system power consumption. Battery life was not measured experimentally under operating conditions. In addition, no IP rating was available, and no specific tests of electrical insulation or safety during handling by children were performed.

Software architecture and digital integration

The prototype's control and communication architecture was structured as a cloud-based client–server model. This model was adopted to centralize the logical server (backend), facilitate its maintenance and updating without modifying the software installed on the robot, and avoid concentrating all processing tasks on the integrated Raspberry Pi microcomputer, whose processing capacity, memory, and storage were more limited than those available on the server. The graphical user interface (frontend) was developed using the React library and hosted on an institutional server, enabling psychology staff to manage sessions and execute commands remotely. The logical server (backend) was implemented in the Python programming language using the FastAPI framework and deployed in an Amazon Web Services (AWS) cloud computing environment through the Elastic Beanstalk platform. Only predefined text and audio files used by the prototype were stored in this environment. No patient data were stored in the version described.

The web interface was structured around an initial control screen from which the professional could access quick messages and activate programmed motor commands for the robot. This initial screen included a quick-message section with 30 predefined phrases frequently used during patient interactions, as well as directional controls to activate programmed movements of the head, hind legs, and tail. The interface also included a dedicated section for accessing the organized content of each of the seven structured psychological sessions. The complete list of quick messages incorporated into the interface is presented in Supplementary Table 3.

In the described functional prototype, the quick messages and predefined audio content were implemented only in Spanish. Although the interface included categories for Indigenous languages, they remained inactive and contained no messages or audio. These categories were incorporated solely as visual elements intended for future linguistic and cultural adaptations.

Functional testing and functional optimization

Once the physical, electronic, and digital components of the prototype had been integrated, functional tests were conducted to verify communication between the web interface operated by the professional and the robot hardware, playback of stories, messages, and predefined responses through the audio system, display of facial expressions on the screen, activation of LED indicators, motor response, and battery operation. These tests did not include measurement of clinical outcomes in patients.

Ethical considerations

The project was approved by the Institutional Research Ethics Committee of the INSN-SB under code PI-934-2025 and Certificate No. 039-2025.

During the user-centered design and requirements definition process, pediatric patients participated in individual surveys and an exploratory group feedback activity after obtaining prior verbal authorization from their parents or guardians and the children's verbal assent, based on their age and capacity to understand. Participation by psychologists from the Hematology Service was voluntary and took place after their prior verbal consent.

The information obtained was used solely for research and prototype development purposes. To protect participant confidentiality, access to the data was restricted to the research team. The activities performed did not involve invasive procedures or modify the patients' routine clinical care.

RESULTS

User-centered design process and requirements definition

In the exploratory survey administered to three hospitalized pediatric patients, two participants preferred an animal morphology over a humanoid appearance. Regarding the type of animal, two preferred a feline morphology, and one preferred a canine morphology. Two participants also preferred the robot to be medium-sized; two selected blue as the preferred color, and two preferred a straight or angular design. All three indicated that the robot should have legs rather than wheels and should incorporate a screen on its face. Two also indicated that it should have a voice. When asked about voice type, all three preferred a female voice. Suggested functionalities included dancing, storytelling, playing, and playing videos and music.

Based on the information obtained during this first stage, an initial proof of concept with a canine morphology was developed using 3D modeling (Figure 1A). This first model was subsequently presented to three hospitalized pediatric patients during an exploratory group feedback activity. Comments addressed the overall shape of the prototype, ear positioning, tail mobility, eye opening and closing, head movements, and posture. Preferences were expressed for ears positioned high or separated from the head, a movable tail, eyes that could open and close, and head movements that could indicate yes and no. The first model's posture was also considered too rigid.

After incorporating the adjustments identified during this phase, an aesthetic validation survey was administered to 10 hospitalized pediatric patients. Nine participants indicated that they liked the robot's shape, and nine considered its appearance friendly; all 10 stated that they would like to have a robot with these characteristics during their hospitalization. In the open-ended question, participants who indicated they liked the prototype cited its resemblance to their own dog, their fondness for dogs, and specific aspects of its appearance, such as its eyes, ears, legs, and size. Features they disliked or considered in need of improvement included the absence of a tail and the possibility of enabling the robot to bark and wag its tail. When asked to select their two preferred options among the color and appearance alternatives presented in the survey, the most frequently selected were Rottweiler (5/10), Dalmatian (4/10), and Scooby-Doo (4/10), followed by light blue (3/10), pink (3/10), and cream and brown (1/10). In the semi-open-ended question, six participants indicated that they did not prefer a breed or color different from the options presented, whereas four proposed other alternatives: an entirely white robot, an orange robot of a smaller breed, a robot resembling a German Shepherd, and a pink or purple robot. The most frequently selected accessories were clothing (8/10), collars (7/10), toys such as bones or balls (5/10), and ears of different shapes (4/10). The most frequently requested activities were playing (8/10), talking (7/10), storytelling (4/10), and helping with homework (4/10). Regarding desired interaction time, five participants selected the option of having the robot available throughout the day, four during the afternoons, one at night, and one for a specified period during each time slot.

These responses were used to adjust the robot's appearance and intended modes of interaction. As a result of the iterative design process, a larger prototype with features more closely resembling those of a real dog was developed (Figure 1B).

Finally, input from psychologists from the Hematology Service helped identify the objectives and activities that are part of routine psychological care for hospitalized patients. Based on this information, robot functionalities that could be integrated into this practice were defined to target psychoeducation, emotional regulation, coping with fear of medical procedures, strengthening self-image, promoting autonomy, and treatment adherence. Functionalities designed for future integration into communication activities involving the child, family, and healthcare team were also incorporated.

Manufactured physical prototype and accessories

As a result of the design, manufacturing, and user-validation process, the physical structure of "Tomy" was produced with a dog-like appearance, consisting of independent PLA parts manufactured via FDM 3D printing and subsequently assembled. Its dimensional compatibility, stability, and suitability for integration of the system's internal components were verified. A stethoscope, flower, hat, and face mask were also manufactured, designed to complement the content intended for the psychological sessions through visual and play-based elements. The final functional prototype and its accessories are shown in Figure 2. Compared with the CAD model presented in Supplementary Figure 1, the battery in the final physical prototype was positioned in a different area inside the body, and both front legs were configured as fixed elements.

Integration of the manufactured structure with electronic components

The final assembly of "Tomy" integrated the 3D-printed shell with the electronic control system centered on a Raspberry Pi microcomputer with 4 GB of RAM. During electromechanical verification, the five stepper motors and the tail servomotor responded to control signals and executed the programmed movements. The number of cycles was not quantified, and no formal success criteria were established.

The power supply system supported simultaneous processing, motor operation, and display use during functional testing. The final functional prototype obtained after the integration process is shown in Figures 1C and 2.

Functional testing and functional optimization

The functional social robot prototype was operated by a psychologist using a tablet connected to the web interface, from which predefined content and commands were selected. The facial display showed four preprogrammed facial expressions (tiredness, happiness, anger, and sadness) (Figure 3), coordinated with the content delivered through the audio system. The five blue LED indicators were observed to activate in response to programmed commands, visually indicating the anatomical regions included in the session content. No quantitative testing was performed, and no formal success criteria were established.

Bidirectional communication between the control interface (frontend), operated by the psychologist, and the robot hardware was verified, with a mean latency of 986 ms. The success rate was not formally evaluated. The interface's initial screen enabled the selection of predefined quick messages and activation of programmed motor commands for the head, hind legs, and tail. The interface also provided access to content for the seven structured psychological sessions via a dedicated section. Predefined messages, stories, and responses were delivered through the prototype's audio system and coordinated with the facial expressions displayed on the screen and the programmed motor actions. Figure 4 shows a view of the initial web interface screen. The cloud module processed requests through the Python backend hosted on the AWS server and enabled communication between the web interface and the robot during functional testing.

The main physical and technical characteristics of the final functional prototype of "Tomy" are summarized in Table 1.

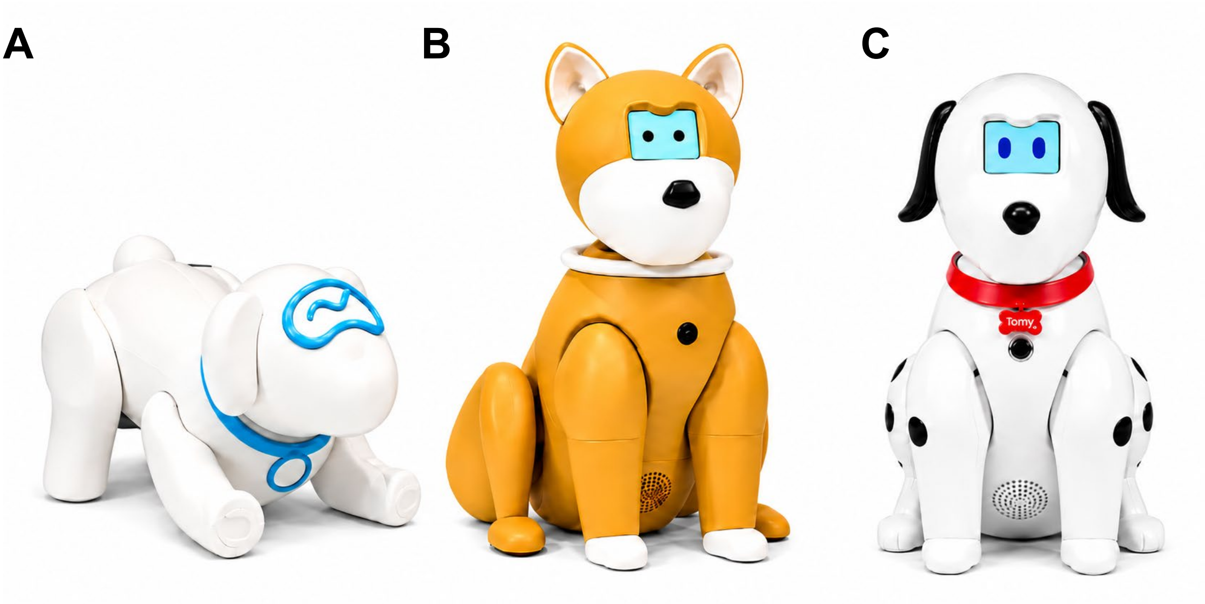

Figure 1. Design and development process of the "Tomy" prototype

A. Initial proof of concept. B. Intermediate prototype. C. Final functional prototype.

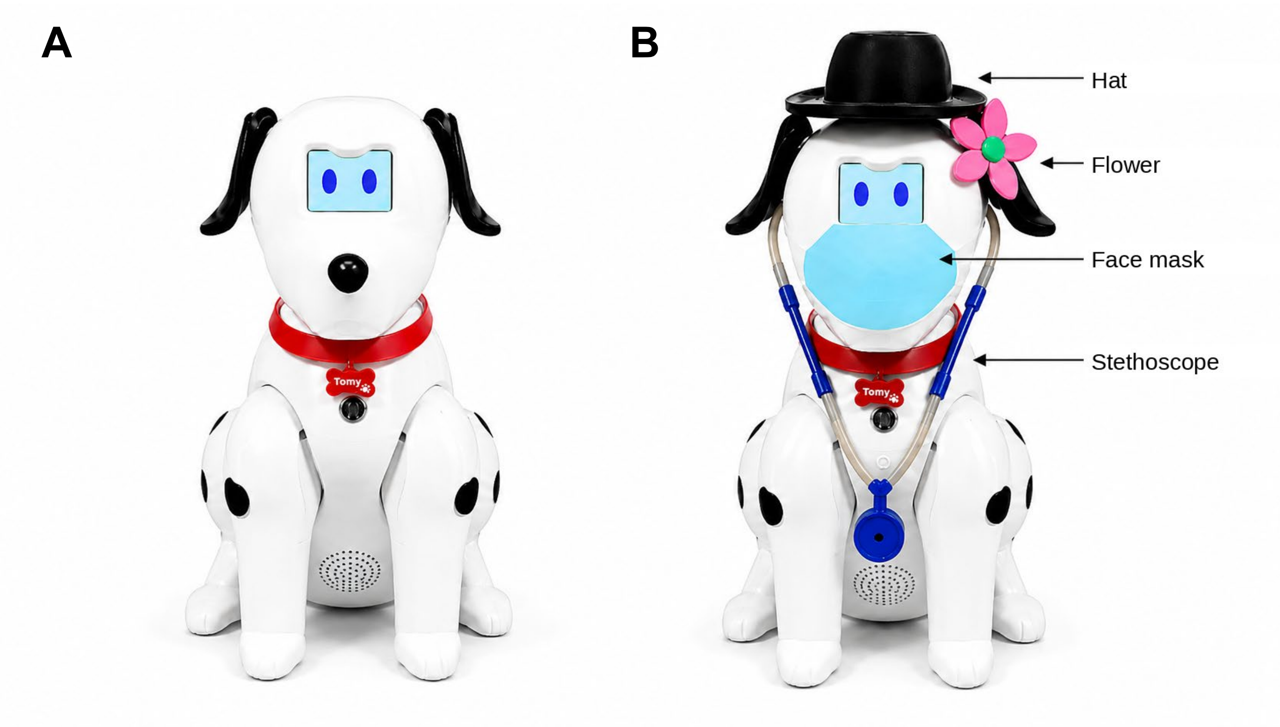

Figure 2. Final functional prototype of "Tomy" and complementary accessories

A. "Tomy" robot without accessories. B. "Tomy" robot with accessories placed in their operating positions: stethoscope, flower, hat, and face mask.

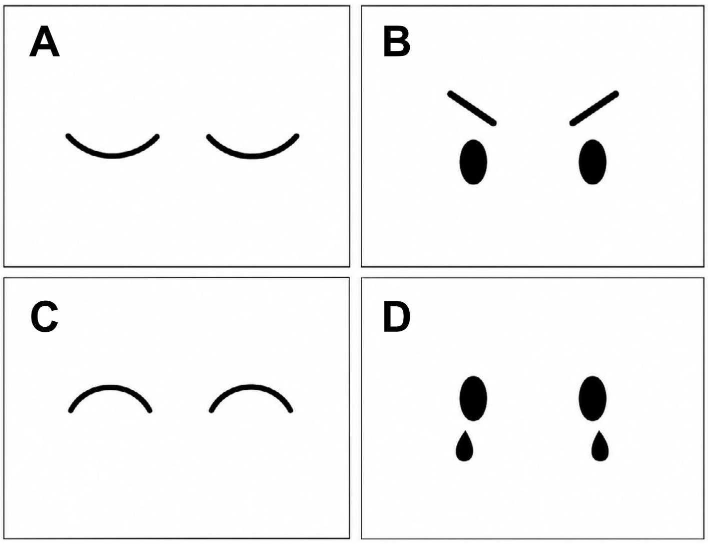

Figure 3. Preprogrammed facial expressions of "Tomy"

A. Tiredness. B. Anger. C. Happiness. D. Sadness.

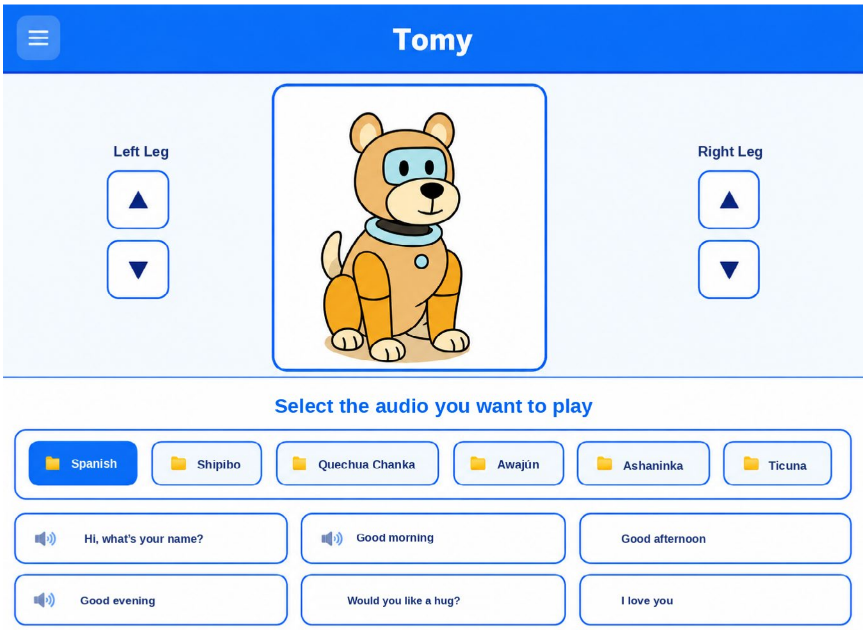

Figure 4. Initial web interface screen for controlling "Tomy"

The quick-message section and motor controls of the web interface are shown. This screen allows the professional to select quick messages, activate the robot's motor commands, and play predefined audio content intended for future integration into the structured psychological sessions. Categories corresponding to Indigenous languages visible in the interface remained inactive and were not included in the functional testing.

Table 1. Physical and technical characteristics of the final functional prototype of "Tomy"

Characteristic	Specification
Weight	2.5 kg
Height	38 cm
Width	24 cm
Depth	42 cm
Estimated theoretical battery life*	2 h (active use) 4 h (normal use)
Programming languages	Python, JavaScript
Connectivity	Wi-Fi
Ports	HDMI

HDMI: High-Definition Multimedia Interface. *Theoretical estimate based on the nominal voltages and maximum currents reported in the electronic component datasheets; not experimentally measured.

DISCUSSION

This study described the design, manufacturing, electronic and digital integration, and functional optimization of "Tomy", a SAR designed as a complementary tool to be used alongside routine psychological care for children hospitalized with hematologic malignancies.

The participation of pediatric patients and healthcare professionals was integrated into the user-centered design process to enhance the prototype's relevance in its intended context of use (12,13). The literature on pediatric social robotics indicates that user-centered design can identify requirements that may be difficult to determine through engineering considerations alone, including robot appearance, modes of interaction, adaptation of language to the child's developmental level, emotional support objectives, and operational constraints within the clinical environment (13). It has also been proposed that robots intended for pediatric settings can be designed more effectively when clinical experts, engineers, and end users collaborate throughout the development process, as this facilitates the definition of behaviors, use scenarios, and implementation conditions tailored to the needs of the child and the healthcare team (14). In line with this approach, the development of "Tomy" incorporated input from hospitalized children and psychologists from the Hematology Service to define its morphology, modes of interaction, play-based resources, and alignment with the objectives of routine psychological care.

As a result of this process, the functional prototype was characterized by a canine morphology and the incorporation of predefined stories, messages, and responses intended for future integration into routine psychological sessions. The robot is controlled through a tablet operated by a psychologist, which provides access to predefined stories, messages, and responses through a web interface for the psychological sessions. In addition, "Tomy" incorporates specific movements of the tail, head, and hind legs; a facial display that can convey expressions associated with the content; and accessories such as a stethoscope, flower, hat, and face mask, designed to complement the content through visual and play-based elements.

Input from the psychologists helped align the robot's functionalities with the objectives and activities of routine psychological care in the Hematology Service. This alignment supports the view of "Tomy" as a complementary resource to be used alongside the professional's activities, rather than as an independent intervention. The prioritized content is also consistent with standards for psychosocial care in pediatric oncology, which include psychoeducation, emotional support, support throughout treatment, and preparation for medical procedures (4,5). Thus, the prototype was defined not only on the basis of technical criteria but also in accordance with patient needs, professional practice, and the conditions of the healthcare setting (15,16).

When "Tomy" is compared with social robots previously reported in pediatric oncology, several experiences with different intended uses and design characteristics can be identified, as summarized in Supplementary Table 4. Alemi et al. (17) used Nima, a humanoid robot based on the commercial NAO platform, as a psychotherapy assistant for children with cancer. The sessions followed previously designed scripts and roles and used a Wizard-of-Oz methodology in which an operator sent commands to the robot at specific times. Nima could speak, perform body gestures, play music, and dance, and the sessions were intended to educate patients about their disease and symptoms, empathize with them, and encourage them to express their fears and concerns. Meghdari et al. (18) described Arash, a mobile humanoid robot designed to entertain, assist, and educate children with cancer in hospital settings. The robot could move through different areas of the hospital, display facial expressions on a screen located in its head, perform body movements, and tell stories. Due to limitations in the Persian-language speech system, voice interaction relied on prerecorded sounds or phrases via a Wizard-of-Oz methodology. MEDiPORT, another humanoid robot based on the NAO platform, was programmed to support children with cancer during needle insertion into subcutaneous ports through verbal messages for preparation, support, guided breathing, and positive reinforcement, coordinated with robot movements and activated at specific moments by an assistant using a tablet, as well as through active distraction involving singing and dancing (19). Other studies have used humanoid robots primarily for educational purposes. van Bindsbergen et al. (20) used the NAO6 robot, presented as "Hero the Sleep Professor," to provide interactive sleep-hygiene education to children with cancer and their parents in a pediatric oncology outpatient clinic through a programmed educational flow with autonomous behavior, questions, feedback, explanatory information, and visual support using a tablet; Lozano-Mosos et al. (21) used NAO V6 to deliver educational messages on nutrition and central venous catheter care to pediatric oncology patients during an individual session in which the robot provided an introduction, movements, and music while the researcher asked questions and the robot delivered educational messages. In Latin America, Colina-Matiz et al. (22) used Lego Mindstorms EV3 as an adjunctive intervention during hospitalization of pediatric oncology patients to stimulate communication, social interaction, and motor activity through social robotics. The intervention was organized into three phases: a brief open-ended story intended to stimulate verbal expression, guided construction of a car-like robot, and cooperative play activities such as races and obstacle courses; because the study was conducted during the COVID-19 pandemic, it also incorporated cleaning and disinfection protocols for the devices used.

These experiences in pediatric oncology are similar to "Tomy" in their use of robotic technologies as complementary, play-based, educational, or emotional-support tools in the care of children with cancer. "Tomy" also shares with Nima the goal of supporting structured psychological interventions led by professionals, and with Arash, an interest in adapting the robot's design to the preferences of pediatric patients and the hospital setting. However, "Tomy" differs from most of the experiences described because it is neither a commercial robot nor a humanoid platform, but rather a locally developed prototype with an animal morphology based on preferences expressed by pediatric patients hospitalized with hematologic malignancies. Furthermore, unlike robots designed for specific procedures, such as needle insertion into subcutaneous ports, or for specific educational modules, such as sleep hygiene, nutrition, or catheter care, "Tomy" was designed for use alongside the psychologist within structured psychological interventions, with content oriented toward emotional support and psychoeducational support during hospitalization.

In addition, some studies in pediatric healthcare have described social robots with animal or pet-like morphologies in hospital settings, whose main characteristics are also summarized in Supplementary Table 4. Moerman and Jansens (23) used PLEO, a baby dinosaur-shaped robot capable of producing animal-like sounds and movements, with hospitalized children, including some undergoing cancer treatment, as a personalized therapeutic activity guided by professionals responsible for play-based and psychosocial support of hospitalized children, with objectives such as distraction, relief from boredom, relaxation, activation, or reduction of distress and stress. Tanaka et al. (24) used aibo, a dog-shaped social robot developed by Sony with a dog-like appearance and behavior, capable of recognizing people, places, and obstacles through cameras and sensors and modifying its behavior in response to tactile or verbal stimuli, with hospitalized pediatric patients with chronic diseases and their caregivers during group sessions intended to promote interaction and support in the pediatric ward. Logan et al. (25) described Huggable, a teddy bear-like robot remotely controlled using a Wizard-of-Oz methodology by pediatric emotional-support staff, in children hospitalized in medical and surgical services, including hematology-oncology units. The operator could activate facial expressions and body actions and communicate through the robot using a modified child-like voice; during the interaction, Huggable conversed with the children, sang children's songs, and played "I spy." Okita (26) used PARO, a therapeutic baby seal-shaped robot, as a robotic companion for pediatric patients admitted to a children's hospital; after a brief explanation of its use, patients could pet, hold, and talk to it.

In Latin America, RoPi represents a regional example of a low-cost social robot designed to provide emotional support to children hospitalized with burns. This animal-shaped prototype was manufactured using 3D printing with PLA and incorporates a display for showing eye expressions, movement mechanisms, and an audio system controlled via a mobile application that also enables voice calls between the patient and family members or professionals. It also includes interchangeable parts to modify its appearance. Compared with "Tomy", RoPi additionally incorporates remote voice communication (10).

These precedents support the relevance of exploring nonhumanoid or animal-like morphologies in pediatric healthcare, particularly when the goal is to promote interaction based on familiarity, play, caregiving, and companionship. In this respect, "Tomy" resembles robots such as PLEO, aibo, Huggable, PARO, and RoPi by adopting an animal appearance to facilitate the child's approach to the device. In addition, exploratory studies of potential applications of social robots in pediatric hospitals have considered biomimetic or pet-like robots, such as MiRo and Joy for All Cat, as potential resources for promoting communication, children's participation in their care, and support during clinical activities (27). However, "Tomy" was designed for a more specific purpose: to serve as a complementary resource, operated by the professional, to be used alongside routine psychological sessions for pediatric patients hospitalized with hematologic malignancies. Its web interface, accessed through a tablet, allows the selection of predefined stories, messages, and responses, as well as the activation of head, tail, and hind-leg movements. Although it cannot move from one location to another, it incorporates a facial display and accessories (stethoscope, flower, hat, and face mask) designed to complement the content intended for sessions conducted in inpatient rooms through visual and play-based elements.

The implementation of social robots in clinical settings presents operational, technical, and ethical limitations that must be considered before their routine incorporation into care. In the case of "Tomy", its eventual implementation will initially require the participation of a psychologist during the sessions, as well as specific training in device operation, because "Tomy" is operated by the professional using a tablet and does not function through direct autonomous interaction with the patient. This is consistent with studies in pediatric oncology suggesting that social robots should be introduced as a complement to care rather than as a replacement for human contact (28). Previous studies also suggest that the acceptability of social robots may vary depending on the patient, their age, familiarity or previous relationship with the robot, and how the device is introduced by the healthcare team; staff should also be informed, trained, and given time to practice before implementation (28). The present study did not evaluate the acceptability of "Tomy" across the seven planned psychological sessions. Consequently, it did not examine changes in interest, the emergence of fatigue, boredom, or rejection, the correspondence between patients' expectations for interaction and the robot's available functionalities, or whether the user experience varied according to age. These aspects should be evaluated in future implementation phases.

The literature has also described barriers related to technical failures, the need for technological support, staff training, additional workload, maintenance, storage, infection control, privacy, and consent (19,22,27). In this context, the present study did not evaluate cleaning and disinfection procedures or other biosafety measures applicable to the prototype. The maximum sound pressure level of the audio system was not determined; no IP rating was available; and no specific electrical insulation or safety tests related to handling by children were performed. These aspects should be evaluated before clinical implementation in accordance with institutional infection prevention and control standards and applicable device safety requirements. These challenges also include the need to adapt the robot's content linguistically and culturally to the healthcare context. The experience with Arash illustrates this issue, as limitations in the Persian-language speech system required the use of prerecorded sounds (18). For "Tomy", this issue will be particularly relevant in future versions because the institution receives pediatric patients from different regions of the country.

Within this framework, the incorporation of an artificial intelligence architecture is being explored to gradually expand the voice-based interaction capabilities of "Tomy" under professional supervision. This architecture could integrate automatic speech recognition, natural language processing, generation of context-aware responses, speech synthesis, and interaction logging for technical traceability purposes. However, these functionalities are not part of the functional prototype described in this study and will need to be evaluated in subsequent stages from technical, ethical, and clinical perspectives before their eventual incorporation into sessions with pediatric patients. In particular, before pilot testing with patients, the incorporation of generative artificial intelligence will require a specific assessment of the safety and clinical appropriateness of generated content. Professional oversight mechanisms and privacy and data protection measures will also need to be established, and the suitability of these functionalities for the context of a hospitalized and vulnerable pediatric population will need to be verified.

Overall, future phases of implementation and evaluation of "Tomy" should address these aspects in patients hospitalized with hematologic malignancies during structured psychological sessions conducted in inpatient rooms and, at least initially, with interaction mediated by a professional using a tablet. These phases should include cleaning, disinfection, and biosafety procedures appropriate to the clinical vulnerability of this population, as well as the progressive evaluation of spoken content or messages in Indigenous languages such as Quechua, Aymara, and Awajún. This adaptation should not be limited to translating stories and messages but should also include cultural adaptation, validation by proficient speakers, and evaluation of acceptability by patients and the healthcare team. Consequently, future phases of evaluation of "Tomy" should include not only emotional outcomes but also indicators of feasibility, safety, acceptability, usability, integration into psychological sessions, and operational sustainability.

In conclusion, a functional social robot prototype with a canine morphology was developed with the participation of hospitalized children and psychologists and designed as a complementary tool to be used alongside routine psychological care for children hospitalized with hematologic malignancies. In its current version, "Tomy" requires guidance from a psychologist and therefore neither replaces the professional nor directly addresses the shortage of specialists.

The present study documented the design, manufacturing, electronic and digital integration, and functional optimization of "Tomy" but did not evaluate its clinical implementation or its effects on anxiety, fear, distress, hospital adaptation, or other emotional outcomes. Future studies should evaluate its safety, feasibility, acceptability, usability, integration into psychological sessions, and added value compared with simpler alternatives, as well as its potential clinical effects and its ability to facilitate the structured delivery of content during psychological care.

Author contributions

OPR: Conceptualization, Investigation, Methodology, Writing – original draft. AMFC: Investigation, Methodology, Writing – original draft. SJPL: Investigation, Methodology, Writing – original draft. RAGA: Conceptualization, Investigation, Methodology, Writing – review and editing. SRCB: Conceptualization, Investigation, Methodology, Writing – review and editing. AJMR: Investigation, Methodology, Writing – review and editing. MPJM: Investigation, Methodology, Writing – review and editing. RMAH: Investigation, Methodology, Writing – review and editing. All authors approved the final version of the manuscript.

Conflicts of interest

The authors declare no relevant financial or non-financial conflicts of interest.

Funding

This project was funded by the Instituto Nacional de Salud del Niño San Borja through the "1.er Concurso de Innovación INSNSB 2023" for a total amount of S/ 50,000.

Data availability

The data supporting the findings of this study are available upon request from the corresponding author.

Use of artificial intelligence

ChatGPT-5.5 was used as a support tool for linguistic editing and grammatical review of the manuscript. The authors reviewed and approved all final content and assume full responsibility for the submitted version.

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