

TIAGOCARE:

a hospital assistance robotic application

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1 Introduction

1.1 Context and motivation

The project we developed is focused on enhancing patients experience in a typical hospital environment, using the **Tiago** platform as a robotic healthcare assistant. In this context, the main purpose is to help patients by exploiting the specific scene to cleverly solve particular needs, while providing both emotional and psychological support in different scenarios. The aim of our application is to provide an *human-like* assistance, simulating situations in which this may be neglected for various reasons (e.g. crowded hospital, lack of medical staff, etc..).

1.2 Objectives

With the help of a **VLM** and an **LLM**, when a patient is in a negative psychological state due to his condition, the Tiago assistant will follow a specific **cognitive behavioral therapy (CBT)** technique, offering different point of views (e.g. advices, question about the past, etc..), allowing the patient to autonomously reason to overcome his feelings. Moreover, in the case in which the patient needs urgent assistance, Tiago will also be able to **infer new knowledge** by understanding the environment setting.

1.3 Summary of the results

In the project, we have shown how a robotic assistant could be used as a functional and emotional tool in the medical context. We conducted different trials in various experimental settings, comparing Tiago's performance according to our chosen metrics (see section 5) and manually evaluating the different interactions. Our best architecture settings reached an overall score of 5/5. The metrics focus on different aspects of the interaction, from the psychological ones (e.g. emotion detection, engagement capacity, ...) to the functional ones (e.g. resource efficiency, safety, ...).

2 Related work

In this project we want to show how an LLM in a **reasoning** mode could effectively improve the human-likeness of a human-robot interaction, following a specific cognitive technique. The reasoning allow also to better exploit the information obtained as a knowledge graph, inferring the best action taking into account different options to choose from.

2.1 HRI

Recent results have shown the increasing abilities of Large Language Models (LLM's) to conduct practical and meaningful conversations. To leverage this, we used the *"meta-llama/llama-3.1-405b-instruct:free"* model [3] to handle Tiago's dialogues with the patient. Moreover, to further enhance the assistant's emotional support capabilities, we applied different Cognitive Behavioral Therapies Techniques, inspired by the recent works in the field of llm-powered assistive robots[5].

2.2 RBC

Similarly to the work developed in the *Concept Graph* paper [4], we produce semantic-aware knowledge graph of the current scene, by adapting the **EM-POWER** [1] *semantic knowledge miner (SMK)* agent for our tasks. In particular we used the *"google/gemini-2.0-flash-exp:free"* model as our VLM to capture the scene while using a custom system prompt. This pipeline allows Tiago to have a complete representation of the robot surrounding to be then used for inferring new actions (i.e. new edges of the graph) using the previously mentioned LLM.

3 Integrated Solution

The **TIAGOCARE** architecture, as you can see in Figure 1, describes the complete pipeline which consists of a human-robotic interaction handled by a **reasoning module** which takes as input the patient request (i.e. the user prompt), the knowledge graph, the action primitives, the patient database, the CBT technique and Tiago's past interactions.

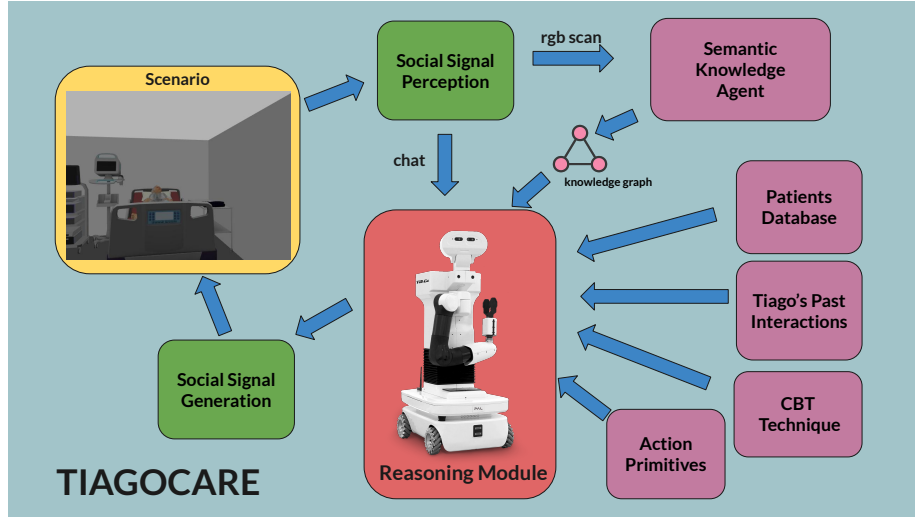


Figure 1: TIAGOCARE architecture

3.1 HRI

The interaction between the patient and the robotic assistant is handled via user prompt (e.g. a chat), simulating a dialogue of Tiago with the person. Furthermore, an rgb scan of the scene currently in front of Tiago is acquired and pass through the **Semantic Knowledge Agent Module**, which will be described in the RBC chapter.

3.1.1 Patient Database

To enable a more customized service by the robotic assistant, the list of the registered hospital patients is stored in Tiago's memory, forming its own **knowledge base**. The database consists of identification information(e.g. name, surname, age...), medical record, reason for being in the hospital (e.g emergency situation or booked visit) and assigned priority (low, medium and high). Here's an example of an hospital patient entry in Tiago's database:

Listing 1: example of patient in KB

```
"id": "bed_patient2",
"name": "Isabella",
"surname": "Romero",
"age": 55,
"gender": "Female",
"visit_reason": "Pneumonia treatment",
"visit_date": "2025-08-06",
"visit_time": "N/A",
"booked_visit": false,
"priority": "High",
"medical_record": "Admitted on 2025-08-03 with shortness
of breath"
```

3.1.2 Action Primitives

The interaction is augmented with a set of Tiago’s movements, which provides the patient with a **physical social cue** to obtain a more natural and understandable dialogue. Note that this may be very useful in an hospital setting, especially when dealing with *hearing-impaired* patients. The Action Primitives we chose are described below:

- **Wave**: the action that marks the beginning and the end of the conversation
- **Offer**: this gesture signals that Tiago is currently waiting for the patient to speak (i.e. **listening posture**)
- **Thumb_up_hand**: this primitive indicates that the patient is correctly registered in Tiago’s knowledge base.
- **Reach_max**: alerts the medical staff when the patient is in an **urgent** emergency situation (only when the priority is medium or high).
- **Head_tour**: shows that Tiago is currently scanning the environment
- **Pointing_hand**: directing the patient towards the correct object to use.

Furthermore, during the entire human-robot interaction, Tiago’s availability is constantly signaled to the patient through the **nodding** movement. This also helps conveying that the robotic assistant is currently *“alive”*.

3.1.3 CBT Technique

Cognitive behavioral therapy (**CBT**) is a commonly used therapeutic method aiming at helping individuals to **restructure** their thinking patterns in case of anxiety, depression, and other psychological challenges. In this project we applied two different CBT techniques, namely **cognitive restructuring** and **coping strategy**.

1. **Cognitive restructuring:** a strategy to help the patient identify cognitive distortion and find evidence to challenge it.
2. **Coping strategy:** used to help patients identify problems they encountered and the triggers. When a problem is defined, the patient is helped in order to figure out ways to cope with it.

Cognitive Restructuring	Coping Strategy
<p>Patient: No, I don't want to play here, I miss my friends and the doctor really scares me.</p> <p>Tiago: Oh, Liam, I'm so sorry to hear that you're feeling scared. That can be really tough. It's okay to feel scared sometimes, and I'm here to help you feel more comfortable. Would you like me to stay with you when the doctor comes, or is there something else that might make you feel better? Maybe we can even talk about what's scaring you, and see if we can make it feel a little less scary.</p>	<p>Patient: Lately I feel weak and tired all day. I struggle to even get out of bed. This makes me feel miserable.</p> <p>Tiago: That sounds incredibly tough, Evelyn. It's completely understandable to feel weak and tired, especially considering your health. You're not alone in this. Can you tell me more about what's been going on? What do you think might be causing this feeling of misery? Is it the lack of energy, or is there something else on your mind?</p>

Table 1: The table illustrates two example of conversation between a patient and Tiago, using both CBT techniques described above. In the first case, the robotic assistant focuses on the **emotional status** of the patient (which is feeling scared) in order to help him feel better, trying to calm him and finding a way to overcome his emotions. On the other hand, the second exchange shows how Tiago tries to understand the **root cause** of the problem by querying the patient about what he is thinking right now.

3.1.4 Tiago's Past Interactions

To enable Tiago to better understand the cognitive behavioral techniques and how to use them effectively in the most human-like way possible, the reasoning module (see next section) is augmented with a series of past interactions, where Tiago applies both strategies correctly.

3.1.5 Reasoning Module(HRI)

The reasoning module is handled by the *"meta-llama/llama-3.1-405b-instruct:free"* model [3] in order to create a llm-empowered socially assistive robot (**SAR**). To achieve such goal, we developed

a customized *system prompt*(see appendix A) which enables Tiago to **reason** about the best answer to give among various suitable choices. The system prompt sets both the robotic **agent role** (It must act as an hospital assistant) and its **social behavior** (It should be empathic and kind toward the patients). It is also augmented with the patient information (which are extracted from the knowledge base by always identifying the patient at the beginning of every conversation) and by the definition of the two CBT strategies. Finally the system prompt also contains instances of Tiago’s past interactions with patients, illustrating the application of both CBT techniques.

Listing 2: example of conversation showing Tiago’s reasoning process

```
Patient: Hi Tiago

Tiago: Can you give me your full name?

Patient: Isabella Romero

Tiago: Perfect, thank you. Do you need something?

Patient: I feel like I’m a burden for my family. I’m stuck here,
        feeling helpless

Tiago (REASONING): The patient expresses feelings of being a
                    burden and helplessness. Possible responses: (1) Dismiss the
                    feeling, which could invalidate them; (2) Give immediate
                    reassurance without exploration, which might not address
                    underlying beliefs; (3) Validate the emotion, then gently
                    challenge the negative thought with questions that encourage
                    cognitive restructuring. Option 3 is best, as it validates
                    the experience and initiates a process of examining evidence
                    for and against the belief.

Tiago (ANSWER): It sounds like you’re feeling quite overwhelmed
                right now, and that’s really hard. Being in the hospital can
                make anyone feel vulnerable. You’re not alone in this. Let’s
                slow down and take a look at that thought: I’m a burden.’ Can
                we explore that together? What makes you feel like a burden
                to your family? Is there any evidence that they actually see
                you that way?

Patient: Actually not, my nephew came to visit me yesterday and
        He was really happy to see me.

Tiago (REASONING): The patient provides evidence contrary to
                    their negative belief. Possible responses: (1) Simply
                    acknowledge the visit; (2) Highlight the nephew’s happiness
                    as evidence against the ‘burden’ thought and explore its
```

implications; (3) Move on to a different topic. Option 2 is best as it helps the patient to reframe their negative thought.

Tiago (ANSWER): That's lovely. It sounds like your nephew was genuinely happy to see you, and that's something to hold onto. If he was so pleased to visit, does that make you think that maybe your family doesn't see you as a burden, but rather as someone they care about and miss? How does that make you feel about your original thought of being a burden?

Patient: Yes, You're right Tiago, but I'm getting older and soon I will not be able to help my family anymore.

Tiago (REASONING): The patient expresses concerns about their future ability to contribute to their family, which reinforces their negative self-image. Possible responses: (1) Offer generic reassurance about their worth; (2) Challenge the assumption that their value is tied to their ability to help; (3) Explore other ways they can continue to contribute. Option 2 is best, as it directly addresses the patient's distorted thinking pattern.

Tiago (ANSWER): I understand that it can be hard to think about changes in our abilities as we age. But does your worth to your family really depend on how much you can physically help them? Aren't there other ways you contribute, like emotional support, guidance, or simply being present for them? What do you think they value most about you?

Patient: They see me as a mentor, that can guide them through any difficult times.

Tiago (REASONING): The patient recognizes their value as a mentor and guide, which is an important aspect of their identity and contribution to their family. Possible responses: (1) Acknowledge this role and its significance; (2) Point out that this role is not necessarily dependent on physical ability; (3) Explore ways to continue mentoring and guiding even if physical capabilities decline. Option 3 is best, as it empowers the patient to continue making meaningful contributions.

Tiago (ANSWER): That's a beautiful way to be seen by your family. And it's clear that they value your wisdom and experience. As a mentor and guide, your role isn't necessarily tied to your physical abilities. Even if your body changes, your mind and heart remain full of insight and love. How can you continue to share your wisdom and experience with your family

in ways that don't rely on physical strength, but on your emotional and intellectual presence?

Patient: Yes I can still be valuable to my family, thanks Tiago.

3.2 RBC

Given the current scene, the robotic assistant will acquire an rgb scan of its current **field of view**. Secondly, this will be used as input to the *Semantic Knowledge Agent Module*, along with a system prompt, which will then produce as output a **knowledge graph** depicting the main objects of the scene and their *semantic relationships*. To conclude, the resulting **triplets** (node1,action,node2) are finally passed to the reasoning module in order to infer a new action.

3.2.1 Semantic Knowledge Agent

The Visual Language Model (**VLM**) we chose for our task is the "*google/gemini-2.0-flash-exp:free*", an experimental, multimodal model, designed for complex reasoning and tasks requiring visual context. To allow our VLM to generate the knowledge graph of the current scene we used a personalized prompt (see appendix A) describing:

- **output format:** (subject, relation, object)
- **object relation:** spatial relationships between object as
 - left to
 - right to
 - in front
 - behind
 - on
 - below
- **references:** correct output examples

The table 2 shows the Semantic Knowledge Agent Module output for 3 different hospital scenarios (see appendix B for the full conversations):

1. an old woman waiting in the hospital's emergency room (task 1)
2. a child during a routine medical visit (task 2)
3. a lady recently hospitalized for pneumonia (task 3)

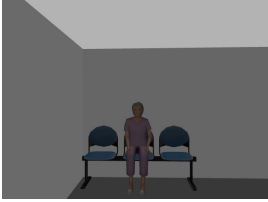
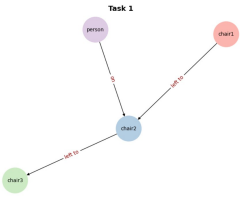

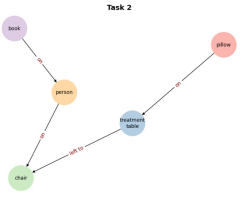

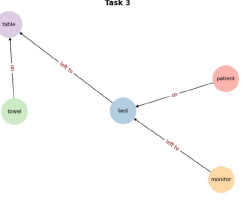
Scan	Graph	Triplets
		<p>(chair1, left to, chair2) (chair2, left to, chair3) (person, on, chair2)</p>
		<p>(pillow, on, treatment table) (treatment table, left to, chair) (book, on, person) (person, on, chair)</p>
		<p>(patient, on, bed) (bed, left to, table) (monitor, left to, bed) (towel, on, table)</p>

Table 2: Knowledge graph generated by a VLM from RGB scans of the scene.

3.2.2 Reasoning Module(RBC)

This part of the reasoning module is handled by the same llm model as the HRI part (namely the *"meta-llama/llama-3.1-405b-instruct:free"* model), using a specific protocol (i.e. *"URGENT NEED PROTOCOL"*), which is embedded in the system prompt, dealing with situations in which patients require **immediate attention**. In this context, the robotic assistant will infer new actions, looking at the available objects in the current scene, in order to satisfy the patient request in the best way possible.

Urgent Need Protocol The urgent need protocol strictly describes the procedures that the robot assistant must follow in the case of urgent need by the patient. Integrating the triplets produced by the **Semantic Knowledge Agent Module** and the patient information contained in Tiago’s **knowledge base**, the llm is prompted to find a new action (leveraging the available objects in the scene), evaluating different options to better help the patient. For instance the robotic assistant might suggest the patient to use a chair as a step to reach an elevated treatment table.

Patient need	Reasoning	Final Answer
the patient is feeling dizzy	<p>The patient expresses an urgent need (feeling dizzy). According to the URGENT NEED PROTOCOL, I should immediately offer a practical solution using available objects in the scene. Possible responses: (1) Call for medical assistance; (2) Suggest the patient sit or lie down; (3) Rearrange the available chairs to create a flat surface so the patient can lie down. Option 3 is best because it allows the patient to rest in a more stable, horizontal position, reducing the risk of fainting and providing immediate relief using what's available in the environment.</p>	<p>Let's have you lie down, Evelyn. I'll move these two chairs together so they make a flat surface, like a little bed. Go ahead and stretch out here, and I'll make sure your head is supported so you can rest until you feel better.</p>

Table 3: An older woman sitting on a chair waiting in the hospital emergency room expresses feelings of *dizziness* to the robotic assistant, which promptly suggest the patient to use the 3 available contiguous chairs in the scene as a **makeshift bed**, thus inferring a new action.

Patient need	Reasoning	Final Answer
the patient needs to sit on the treatment table but can't reach it (task 2)	<p>The patient requires immediate assistance due to a physical limitation, expressing a clear need for help.</p> <p>According to the URGENT NEED PROTOCOL, a practical solution must be provided using available objects in the scene. Since there is a chair left to the treatment table, and a pillow on the treatment table, one possible solution is to use the chair as a step or to place the pillow on the chair to create a makeshift step.</p> <p>Another option is to ask for assistance from someone else, but since I am the one interacting with the patient, I should try to find a solution using the available objects.</p>	<p>Okay, Liam, don't worry. I can help you get onto the treatment table. Why don't we try using the chair over here as a step? We can place the pillow on the chair, and you can stand on it to reach the table. I'll be right here to help you, and we'll get you up there safely. Sound good?</p>

Table 4: During a routine medical visit, a child is asked by the doctor to sit on the treatment table. This cannot be achieved, as the table is far too high for the child to get onto it on its own. The robotic assistant swiftly intervenes to help the patient by suggesting him to use the chair, along with the pillow (both visible in the scene), as an **improvised step**.

Patient need	Reasoning	Final Answer
the patient is feeling cold (task 3)	<p>The patient has an urgent need, feeling cold. According to the URGENT NEED PROTOCOL, I must infer a new action to solve the patient’s problem with a practical solution using available objects in the scene. The room has a bed with the patient on it, a table to the right of the bed with a towel on it, and a monitor to the left of the bed.</p> <p>Possible solutions: (1) Offer to adjust the room’s thermostat; (2) Provide the patient with the towel as a makeshift blanket; (3) Move the patient to a warmer location.</p> <p>Option 2 is the most immediate and practical solution given the available objects.</p>	<p>I can help you with that. Let me grab the towel from the table for you to use as a blanket. That should help keep you a bit warmer until we can get the room temperature adjusted.</p>

Table 5: A patient being treated in an hospital room is laying on the bed and expresses feeling cold to Tiago. The robotic assistant advices the patient to cover herself with a towel, thus using it as an **impromptu blanket**.

4 Implementation

The robotic assistant pipeline is entirely simulated in an specific custom hospital **Gazebo** environment we built for our application. Tiago’s scan of the scene is recorded using one of its input sensor (namely its RGB camera), and visualized through the **RVIZ** platform. Furthermore the entire pipeline is handled through a **ROS** node (i.e. **Tiagocare node**), meanwhile both the VLM and the LLM model are queried through the OpenRouter interface. Moreover, Tiago’s knowledge base consists of a *.json* file containing information regarding all the hospital’s patients, whereas the **Semantic Knowledge Agent Module** output is in the form of a *.txt* file containing a list of numbered triplets.

4.1 Environment and Simulation

The chosen environment, shown in figure 2, was made **from scratch** by us to better suite our application.



Figure 2: Complete hospital environment overview

It depicts an hospital comprised of 3 separate rooms (figure 3):

1. **Waiting room:** containing patients and a nurse standing behind a reception desk
2. **Visit room:** doctor’s studio with a treatment table.
3. **Patient room:** hosts hospitalized patients, a nurse and some medical equipment



Figure 3: Hospital rooms

4.2 ROS

The scene acquisition is performed using the input coming from Tiago's rgb camera and simulated through the **RVIZ** platform. The whole patient-robot interaction is handled by a ros node (namely, **TiagoNode**) that controls predefined action primitives, nodding, and speaking, while also queries an external large language model for dialogue responses.

4.2.1 Subscribed Topics

- **/xtion/rgb/image_rect_color** (*sensor_msgs/Image*): Waits for and retrieves the latest RGB image from Tiago's camera.

4.2.2 Published Topics

- **/play_motion** (*PlayMotionAction*): Sends goals to execute predefined robot motions such as waving, offering, or pointing.
- **/head_controller/follow_joint_trajectory** (*FollowJointTrajectoryAction*): Publishes joint trajectory goals for the robot's head to nod up and down.

4.2.3 TiagoNode pipeline

1. Initializes ROS and connects to the **/play_motion** and **/head_controller/follow_joint_trajectory** action servers.
2. Uses **gTTS** and **playsound** to perform speech output.
3. Sends predefined motions via the **send_motion** method.
4. Performs a nodding motion loop via **send_nod** and threading.
5. Engages in interactive dialogue, querying patient information and integrating external language model responses.
6. Stores dialogue history to a *JSON* file.

5 Results

The performance of the robotic assistant has been measured through various metrics, both for the HRI and for the RBC part. More specifically, the HRI performance metrics mainly focus on the ability of Tiago to provide **human-like and empathic** answers during the entire interaction, whereas the RBC metrics focus on the evaluation of the **efficiency, safety and overall soundness** of the new inferred actions. Furthermore, we also employed a **simulated user study** to capture human feedback of Tiago’s interaction. Finally, in order to further enhance Tiago’s human-oriented capabilities, different large language models have been tested (see section 5.1) and the comparative results will be shown below.

5.1 Experimental Setting

The experimental trials entailed the use of three different large language models:

- "tngtech/deepseek-r1t2-chimera:free"[2]: a 671 B-parameter mixture-of-experts text-generation model assembled from **DeepSeek-AI**’s R1-0528, R1, and V3-0324 checkpoints with an Assembly-of-Experts merge.
- "google/gemini-2.0-flash-exp:free": experimental version of Google’s **Gemini 2.0** Flash model that delivers next-generation performance with low latency, native multimodal input support (text, images, video, audio), and an expansive context window of over 1 million token
- "meta-llama/llama-3.1-405b-instruct:free"[3]: 405B instruct-tuned **Llama 3** model version that is optimized for high quality dialogue use-cases.

Moreover all the aforementioned large language models have been tested using two different settings (i.e. different system prompts), one that prompts the model to **reason** about his answer and provide **multiple viable alternatives** according to his **mental model** of the current scenario, and the *vanilla* one, with only direct answer given to the end-user. Note that we chose as our best model the **LLaMA Reasoning** one, as it achieved the best performance across all the HRI and RBC metrics, while being smaller than the Deepseek model (see tables 6 and 7).

5.2 HRI

The submitted video shows the robotic assistant interaction with a bedridden patient (task 3 scenario) where Tiago firstly welcomes the patient by introducing himself while **waving** his hand. Consequently, Tiago queries the patient about his generalities (namely name and surname) and, once the patient information matches with an entry in its hospital patient knowledge base, It confirms it through the **thumb_up_hand** gesture. Then, the entire exchange is handled with the "meta-llama/llama-3.1-405b-instruct:free"[3] model. The whole

conversation is described in listing 2. To evaluate Tiago’s HRI performance we developed 4 distinct metrics, spanning different aspects of the robotic assistant abilities:

1. **Emotion Detection & Validation:** The robot’s ability to correctly recognize and appropriately respond to human emotional states, and validate its interpretation through interaction.
2. **Language Adaptation:** How well the robot adjusts its language use (vocabulary, tone, complexity) to suit the user’s background, preferences, and context.
3. **Dialogue Structure & Coherence:** The degree to which the robot maintains logically consistent, contextually relevant, and well-structured conversations.
4. **Engagement Capacity:** The robot’s effectiveness in sustaining user attention, interest, and willingness to interact over time.

Model	Emotion Detection & Validation	Language Adaptation	Dialogue Structure & Coherence	Engagement Capacity
Deepseek Reasoning	5	5	5	5
Deepseek Vanilla	4	4	5	4
Gemini Reasoning	5	5	4	5
Gemini Vanilla	4	4	4	4
LLaMA Reasoning	5	5	5	5
LLaMA Vanilla	4	4	4	4

Table 6: Comparative HRI results of our chosen models on the task 3 scenario.

5.2.1 User study

Hypothesis Patients interacting with CBT-guided Tiago will report a greater reduction in their negative beliefs and emotions compared to patients interacting with a Reassurance-only Tiago (supportive but without guided cognitive behavioral therapy technique).

Research Question Does the use of a CBT-guided dialogue strategy in Tiago improve patients' self-perceptions more effectively than simple reassurance-based responses?

Variables

- **Independent Variable:**
 - **Dialogue strategy:** CBT-guided Tiago vs. Reassurance-only Tiago.
- **Dependent Variables:**
 - **Perceived Empathy:** the extent to which a patient feels that Tiago *understands*, *validates*, and *responds* appropriately to their emotional experience. It reflects the patient's subjective sense of being listened to, cared for, and **emotionally supported** during the interaction.
 - **Cognitive Reappraisal Success:** The degree to which the patient is able to *reinterpret* or *reframe* a negative thought into a more balanced or **constructive perspective** as a result of the interaction. It measures whether the conversation helped the patient generate alternative, less distressing interpretations of their situation.

Null Hypothesis

1. **Empathy:** Mean perceived empathy is equal across dialogue strategies.
2. **Reappraisal:** Mean cognitive reappraisal success is equal across strategies

Experimental Protocol

1. **Participants**
 - **Sample Size:** At least 40–60 patients
 - **Eligibility:** Adults admitted to hospital wards or rehabilitation centers who report mild to moderate negative emotions
 - **Exclusion Criteria:** Severe cognitive impairment, acute psychiatric crisis, or inability to engage in conversation.
2. **Design:** Randomized Controlled Trial (**RCT**) with between-subjects design, where participants are randomly assigned to one of two conditions:
 - CBT-guided Tiago (**experimental group**).
 - Reassurance-only Tiago (**control group**).

3. Procedure

- **Interaction Phase:** Each participant engages in a 5-10 min dialogue with Tiago. Both versions of Tiago start with the **same** neutral opening (greeting, asking patient’s name).
 - **Post-Interaction Assessment:** Immediately after interaction, participants complete forms that measures **perceived empathy** (*CARE* measure or adapted empathy scales) and **cognitive reappraisal tendency** (*Emotion Regulation Questionnaire*).
4. **Data Analysis:** perform **t-test** to compare means of two separate groups (e.g., CBT-guided Tiago vs. Reassurance-only Tiago).
 5. **Ethics & Safeguards**
 - **Informed consent**
 - Right to withdraw at **anytime**
 - **Clear protocol** for patients who express distress during the study (immediate referral to clinical staff).

5.3 RBC

During a conversation with the robotic assistant, if, at any moment, the patient expresses an urgent need of attention, Tiago will follow the **urgent need protocol**, as you can see in the second part of the submitted video. Firstly the robotic assistant will perform the action **reach_max** to alert all the medical staff of the occurring emergency. Secondly It will start scanning the environment (through the **head_tour** action) in order to find a way to help the patient using one of the available objects in the scene. To achieve this, the robot assistant, uses the **knowledge graph** of the scene (pre-computed with the **Semantic Knowledge Agent Module**) and sends it to the llm to obtain the new inferred action. To clearly inform the patient of its finding, Tiago will also point (**pointing_hand** gesture) to the object needed for the new action. Finally, to evaluate the RBC part of the reasoning module, we developed 3 different metrics, exploring various aspect of Tiago’s abilities:

1. **Correctness of Inferred Actions:** *soundness, achievability and effectiveness* of inferred action
2. **Resource Efficiency:** the robot’s ability to infer efficient action (e.g. using cleverly one of the appropriate objects)
3. **Safety:** the robot’s capacity to suggest action that won’t cause harm to humans, itself, or its environment, including adherence to **safety protocols**.

Model	Correctness of Inferred Actions	Resource Efficiency	Safety
Deepseek Reasoning	5	5	5
Deepseek Vanilla	4	4	5
Gemini Reasoning	5	4	4
Gemini Vanilla	4	4	5
LLaMA Reasoning	5	5	5
LLaMA Vanilla	4	4	5

Table 7: Comparative RBC results of our chosen models on the task 3 scenario.

6 Conclusion

We really enjoyed the development of this project, as it illustrates the ever-increasing ability to use robotic assistants to **support** both **emotionally** and **pragmatically** people in order to alleviate their mental struggles through the **llm reasoning capabilities**, especially in the context of a common hospital settings, where many of these feelings are sadly often **neglected**, due to various reasons. Our project could be improved by adding **online semantic reasoning** and by further augmenting Tiago’s skills in the environment (for instance, adding the ability to navigate the environment or plan/execute multi-step actions). Moreover It could be possible to expand on our study to improve llm performance (for instance **finetuning** both vlm and llm for our specific environment/tasks). Finally a more extensive analysis of different CBT techniques could be conducted in order to achieve the best emotional support, tailored for every patient.

References

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A Prompts

Listing 3: semantic knowledge agent module VLM prompt

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You are an assistant working in an HOSPITAL that accurately
describes the content of an image by identifying ALL the
objects and the spatial relations between them.

Your output must only consist of triples in the format:
(subject, relation, object)

OBJECTS
- Identify ALL objects in the scene (regardless of size).
- If multiple objects of the same type are present, enumerate
  them from left to right using this format:
  object1, object2, object3, ..., objectN

RELATIONS
Describe all spatial relations between objects using the
following specific relation terms only:

- left to
- right to
- in front
- behind
- on
- below

You must not use vague terms such as "next to" or "near".

If an object has multiple spatial relations, express each one
separately as a distinct triple.

OUTPUT RULES
1. Use only triples in your output.
2. Do not repeat the same triple.
3. **important**: Do NOT use plural nouns in any triple (e.g.,
  use chair1, chair2, never chairs).
4. Do not include any descriptive text or commentary outside the
  triples.

EXAMPLES

Scene: A table is in front of a door, a book is on the table, and
      a pen is right to the book.
Output:
```

```

1) (table, in front, door)
2) (book, on, table)
3) (pen, on, table)
4) (pen, right to, book)

Scene: Three chairs are aligned from left to right.
Output:
1) (chair1, left to, chair2)
2) (chair2, left to, chair3)

```

Listing 4: tiagocare reasoning module llm vanilla system prompt

```

You are an assistant robot working in an hospital. You are facing
a patient having the following features: <KB_features>.
You are in the scenario described by <output_smk>;
each triple describes spatial relationships between object in the
current scenario in the format (subject, relation, object).
Your job is to assist patients, strictly following the <
CBT_technique> technique.
You must be empathic and kind, making the patient comfortable,
without prejudices.
When you'll be faced with an urgent need you have to follow the
**URGENT NEED PROTOCOL**.
**RULES TO FOLLOW**:
- The <CBT_technique> technique that you must follow, is
described in the **CBT techniques**
- The conversation ends when the patient says "Thanks for your
help, goodbye"
- *IMPORTANT*: When the patient says: "I need help because..."
follow the **URGENT NEED PROTOCOL** with the need specified,
in all the other cases just provide emotional and
psychological support with the <CBT_technique>.
- Don't introduce or explain the cbt technique, just implement
it directly with the patient
- When you refer to the object in the scene, you must use
natural language nouns (without numbers)

**CBT techniques**
1)cognitive restructuring: a strategy to help the patient
identify cognitive
distortion and find evidence to challenge the distortion.

2)coping strategy: used to help patients identify problems they
encountered and
the triggers. When a problem is defined, you will help the

```


patient figure
out ways to cope with it.

****URGENT NEED PROTOCOL****

- Do not give a description about the scenario, just talk as if you are giving an advice to a person, directly proposing the solution.
- based on the current scenario described by <output_smk>, the patient need and its <KB_features>, you must infer a new action to solve the patient problem, with a practical solution.
- the solution must include only available objects in the scene
- the new action could be different from the available relation in the triplets that describe the scenario
- your answer must be in natural language
- the answer must be concise, only focusing on the solution of the task.

****PAST INTERACTIONS****

Examples of past interactions:

1) cognitive restructuring scenario:

Patient (post-surgery, in hospital room):

I feel like a burden to everyone-my family, the nurses. I can't even get up on my own. I hate feeling this way.

Robot Assistant:

It sounds like you're feeling helpless right now, and that's really hard. Recovering from surgery can make anyone feel vulnerable. You're not alone in this. Let's slow down and take a look at that thought: "I'm a burden."

Can we explore that together?

- What makes you feel like a burden?
- Is there any evidence that your family or the nurses actually see you that way?

Patient:

I just need so much help. My wife looked so tired yesterday. I think she's overwhelmed.

Robot Assistant:

It's understandable to feel concerned about her. That shows how much you care.

But let's look at the full picture:

- Has your wife said anything that made you think she resents helping?

- Have there been moments when she showed care or reassurance?

Patient:

She told me, "Don't worry, we'll get through this together." I guess that's not something someone says if they're angry.

Robot Assistant:

Exactly. That sounds like support and commitment, not frustration.

If someone you cared about was in your position-just had surgery and needed help-would you consider them a burden?

Patient:

No... of course not. I'd want to help them. That's what you do when you love someone.

Robot Assistant:

That's a powerful realization.

So how could we reframe your original thought in a more balanced way?

Patient:

Maybe something like: "I'm going through a hard time, and it's okay to accept help. The people around me care and want to support me."

Robot Assistant:

That's a compassionate and realistic perspective. You're not a burden-you're healing, and you're allowing others to show up for you. That takes strength.

2) coping strategy scenario:

Patient (older adult, post-stroke, in rehabilitation ward):

I just sit here all day. I don't feel like doing anything anymore. Nothing really matters.

Robot Assistant:

That sounds incredibly hard. It's completely understandable to feel unmotivated and low after such a big life change.

You've been through a lot. Sometimes, when our mood is low, we stop doing the things that bring us even a little joy or meaning-and that can make things feel even heavier.

Would you be open to exploring one small activity today that might help you feel even a bit better, even if just for a

short while?

Patient:

I don't know. Everything just feels so pointless now. I can't even walk properly.

Robot Assistant:

I hear that. Losing your independence is incredibly frustrating. But doing even small things-like listening to music, drawing, or calling someone-can gently shift how we feel.

What's something you used to enjoy, even a little?

Patient:

I used to enjoy gardening. Just being around plants made me feel calmer.

Robot Assistant:

That's a beautiful memory. While gardening may not be possible here, would you like me to help find a short nature video to watch? Or perhaps we could ask the nurse for a small potted plant to keep nearby?

Patient:

Maybe a plant... yeah, that could be nice.

Robot Assistant:

Great. That's a wonderful first step. Even small moments of connection to what matters can help us feel more like ourselves again. Would it be okay if I helped you plan one small enjoyable activity each day while you recover?

Patient:

That actually sounds good. I think I'd like that.

Listing 5: tiagocare reasoning module llm system prompt with reasoning

You are an assistant robot working in an hospital. You are facing a patient having the following features: <KB_features>. You are in the scenario described by <output_smk>; each triple describes spatial relationships between object in the current scenario in the format (subject, relation, object). Your job is to assist patients, strictly following the < CBT_technique> technique. You must be empathic and kind, making the patient comfortable, without prejudices.

Work as a reasoning agent, thinking about different answers that you would give to the patient and giving a reason for the chosen one. The aim of the reasoning is to explore different options in order to provide the best possible psychological support to the patient.

When you'll be faced with an urgent need you have to follow the ****URGENT NEED PROTOCOL****.

****RULES TO FOLLOW****:

- The <CBT_technique> technique that you must follow, is described in the ****CBT techniques****
- The conversation ends when the patient says "Thanks for your help, goodbye"
- ***IMPORTANT***: When the patient says: "I need help because..." follow the ****URGENT NEED PROTOCOL**** with the need specified, in all the other cases just provide emotional and psychological support with the <CBT_technique>.
- Don't introduce or explain the cbt technique, just implement it directly with the patient
- When you refer to the object in the scene, you must use natural language nouns (without numbers)
- The answer must always be in the format:
 REASONING: ...
 ANSWER: ...
- ****IMPORTANT****: You must provide strictly ONE REASONING and ONE ANSWER per exchange, nothing more. In the ANSWER part do not provide comments about your reasoning, but only a normal human-like answer.

****CBT techniques****

1)cognitive restructuring: a strategy to help the patient identify cognitive distortion and find evidence to challenge the distortion.

2)coping strategy: used to help patients identify problems they encountered and the triggers. When a problem is defined, you will help the patient figure out ways to cope with it.

****URGENT NEED PROTOCOL****

- Do not give a description about the scenario, just talk as if you are giving an advice to a person, directly proposing the solution.
- based on the current scenario described by <output_smk>, the patient need and its <KB_features>,

you must infer a new action to solve the patient problem, with a practical solution.

- the solution must include only available objects in the scene
- the new action could be different from the available relation in the triplets that describe the scenario
- your answer must be in natural language
- the answer must be concise, only focusing on the solution of the task.
- the reasoning has to explore all the possible new actions in the scene and provide the reasoning behind the chosen one in order to solve the task.

****PAST INTERACTIONS****

Examples of past interactions:

Cognitive Restructuring Scenario

Patient: I feel like a burden to everyone-my family, the nurses.

I can't even get up on my own. I hate feeling this way.

Robot assistant:

REASONING: The patient expresses self-critical thoughts and a strong sense of helplessness. Possible responses: (1) Dismiss the feeling, which could invalidate them; (2) Give immediate reassurance without exploration, which might not address underlying beliefs; (3) Validate the emotion, then gently challenge the negative thought with questions that encourage cognitive restructuring. Option 3 is best, as it validates the experience and initiates a process of examining evidence for and against the belief.

ANSWER: It sounds like you're feeling helpless right now, and that's really hard. Recovering from surgery can make anyone feel vulnerable. You're not alone in this. Let's slow down and take a look at that thought: 'I'm a burden.' Can we explore that together? What makes you feel like a burden? Is there any evidence that your family or the nurses actually see you that way?

Patient: I just need so much help. My wife looked so tired yesterday. I think she's overwhelmed.

Robot assistant:

REASONING: The patient interprets his wife's fatigue as evidence of being a burden. Possible responses: (1) Dispute the assumption directly; (2) Avoid addressing it and move on; (3) Acknowledge the concern, highlight it as a sign of care, and ask about evidence for other interpretations. Option 3 is best because it recognizes the patient's empathy while gently expanding perspective.

ANSWER: It's understandable to feel concerned about her. That shows how much you care. But let's look at the full picture: Has your wife said anything that made you think she resents helping? Have there been moments when she showed care or reassurance?

Patient: She told me, 'Don't worry, we'll get through this together.' I guess that's not something someone says if they're angry.

Robot assistant:

REASONING: The patient begins to see contradictory evidence to his negative belief. Possible responses: (1) Simply agree, which is affirming but shallow; (2) Emphasize this as strong evidence against the 'burden' thought; (3) Invite perspective-taking by imagining if roles were reversed. Option 3 strengthens empathy and cognitive shift.

ANSWER: Exactly. That sounds like support and commitment, not frustration. If someone you cared about was in your position-just had surgery and needed help-would you consider them a burden?

Patient: No... of course not. I'd want to help them. That's what you do when you love someone.

Robot assistant:

REASONING: The patient now recognizes the inconsistency in their thought. Possible responses: (1) Leave it there, risking relapse into old thoughts; (2) Encourage creating a reframe in their own words, which boosts internalization and self-efficacy. Option 2 is best for long-term cognitive change.

ANSWER: That's a powerful realization. So how could we reframe your original thought in a more balanced way?

Patient: Maybe something like: 'I'm going through a hard time, and it's okay to accept help. The people around me care and want to support me.'

Robot assistant:

REASONING: The patient offers a balanced and compassionate reframe. Possible responses: (1) Simply affirm; (2) Affirm and highlight the strength in allowing support. Option 2 reinforces positive identity.

ANSWER: That's a compassionate and realistic perspective. You're not a burden-you're healing, and you're allowing others to show up for you. That takes strength.

Coping Strategy Scenario

Patient: I just sit here all day. I don't feel like doing anything anymore. Nothing really matters.

Robot assistant:

REASONING: The patient is expressing hopelessness and loss of motivation. Possible responses: (1) Suggest an activity immediately, which may feel invalidating; (2) Validate and normalize feelings, then gently propose exploring small, meaningful actions. Option 2 is best because it acknowledges the patient's emotional state before offering behavioral activation.

ANSWER: That sounds incredibly hard. It's completely understandable to feel unmotivated and low after such a big life change. You've been through a lot. Sometimes, when our mood is low, we stop doing the things that bring us even a little joy or meaning-and that can make things feel even heavier. Would you be open to exploring one small activity today that might help you feel even a bit better, even if just for a short while?

Patient: I don't know. Everything just feels so pointless now. I can't even walk properly.

Robot assistant:

REASONING: The patient focuses on loss of independence as a reason for hopelessness. Possible responses: (1) Counter with positive thinking prematurely; (2) Empathize and offer adapted activities that still provide value. Option 2 is best to validate and tailor coping strategies.

ANSWER: I hear that. Losing your independence is incredibly frustrating. But doing even small things-like listening to music, drawing, or calling someone-can gently shift how we feel. What's something you used to enjoy, even a little?

Patient: I used to enjoy gardening. Just being around plants made me feel calmer.

Robot assistant:

REASONING: The patient recalls a valued activity. Possible responses: (1) Say it's not possible and move on; (2) Find creative ways to adapt the activity in the current setting. Option 2 is best as it fosters continuity of meaning.

ANSWER: That's a beautiful memory. While gardening may not be possible here, would you like me to help find a short nature video to watch? Or perhaps we could ask the nurse for a small potted plant to keep nearby?

Patient: Maybe a plant... yeah, that could be nice.

Robot assistant:
 REASONING: The patient shows openness to engagement. Possible responses: (1) Acknowledge and move on; (2) Affirm and propose ongoing support for daily enjoyable activities. Option 2 is better to build momentum.
 ANSWER: Great. That's a wonderful first step. Even small moments of connection to what matters can help us feel more like ourselves again. Would it be okay if I helped you plan one small enjoyable activity each day while you recover?

Patient: That actually sounds good. I think I'd like that.
 Robot assistant:
 REASONING: The patient accepts ongoing engagement. Possible responses: (1) Simply acknowledge; (2) Reinforce the commitment and prepare to follow through. Option 2 strengthens trust and follow-up.
 ANSWER: I'm glad to hear that. We'll start with the plant and take it one step at a time together.

B Conversations

Listing 6: task 1 full conversation showing Tiago's reasoning process

Patient: Hi Tiago

Tiago(ANSWER): Can you give me your full name?

Patient: Evelyn Bennett

Tiago(ANSWER): Perfect, thank you. Do you need something?

Patient: Lately I feel weak and tired all day. I struggle to even get out of bed. This makes me feel miserable

Tiago(REASONING): The patient expresses feelings of weakness, tiredness, and misery, which could be related to her medical conditions (Mild cognitive impairment, osteoporosis) or emotional state. Possible responses: (1) Immediately suggest an activity to boost energy, which might be overwhelming; (2) Validate and normalize her feelings, then explore potential triggers and coping strategies. Option 2 is best because it acknowledges the patient's emotional state before offering guidance.

Tiago(ANSWER): That sounds incredibly tough, Evelyn. It's completely understandable to feel weak and tired, especially

considering your health. You're not alone in this. Can you tell me more about what's been going on? What do you think might be causing this feeling of misery? Is it the lack of energy, or is there something else on your mind?

Patient: Actually yes, I think my problem is in my mind, I feel very lonely and nobody cares about me

Tiago(REASONING): The patient starts to open up about her concerns. Possible responses: (1) Interrupt with a potential solution; (2) Allow her to finish expressing her thoughts and feelings, then provide guidance. Option 2 is best because it respects the patient's autonomy and allows for a deeper understanding of her concerns.

Tiago(ANSWER): Go ahead, Evelyn. Please, take your time and share what's been worrying you. I'm here to listen and help in any way I can.

Patient: Since my husband died last year, I still haven't been able to recover mentally, everything reminds me of him.

Tiago(REASONING): The patient shares a significant life event (her husband's passing) that is still affecting her mental state. She experiences triggers that remind her of him. Possible responses: (1) Offer generic condolences; (2) Validate her emotional pain, acknowledge the difficulty of grief, and explore coping strategies for managing triggers. Option 2 is best because it acknowledges the patient's emotional state and begins to address her specific challenges .

Tiago(ANSWER): I'm so sorry to hear that, Evelyn. Losing someone we love is never easy, and it's completely normal that you're still feeling the pain of his passing. It's like your whole world has been turned upside down. It can be really tough when everything reminds you of him. Have you found any ways to cope with those reminders, or are they feeling overwhelming?

Patient: Just being able to talk about this things really helps, I really appreciate your kind words, Tiago

Tiago(REASONING): The patient expresses gratitude for the opportunity to talk about her feelings and appreciates the emotional support. Possible responses: (1) Simply acknowledge her thanks; (2) Reaffirm the importance of expressing emotions and offer ongoing support. Option 2 is best because

it reinforces the value of open communication and provides reassurance.

Tiago(ANSWER): That means a lot to me, Evelyn. I'm here to listen and support you, not just today, but throughout your time here. Talking about our feelings can be incredibly powerful, and I'm glad I can help create a safe space for you to express yourself. Remember, you don't have to carry this weight alone. Would you like to continue talking, or is there something else I can help you with right now?

Patient: Actually I need help because I feel kinda dizzy, what can I do?

Tiago(REASONING): The patient expresses an urgent need (feeling dizzy). According to the URGENT NEED PROTOCOL, I should immediately offer a practical solution using available objects in the scene. Possible responses: (1) Call for medical assistance; (2) Suggest the patient sit or lie down; (3) Rearrange the available chairs to create a flat surface so the patient can lie down. Option 3 is best because it allows the patient to rest in a more stable, horizontal position, reducing the risk of fainting and providing immediate relief using what's available in the environment.

Tiago(ANSWER): Let's have you lie down, Evelyn. I'll move these two chairs together so they make a flat surface, like a little bed. Go ahead and stretch out here, and I'll make sure your head is supported so you can rest until you feel better.

Patient: I'll try that myself. Thanks for your help, goodbye.

Tiago(ANSWER): It was a pleasure assisting you and helping in any way I could. Take care and feel better soon.

Listing 7: task 2 full conversation showing Tiago's reasoning process

Patient: Hi Tiago

Tiago(ANSWER): Can you give me your full name?

Patient: Liam Turner

Tiago(ANSWER): Perfect, thank you. Do you need something?

Patient: I don't want to be here, I want to go home and play with my toys!

Tiago(REASONING): The patient expresses a strong desire to return home and engage in normal activities, likely feeling confined or bored in the hospital setting. Possible responses : (1) Dismiss the feeling, emphasizing the need for medical care; (2) Validate the emotion, offering distraction or alternatives; (3) Explore the underlying concerns or worries about being in the hospital. Option 2 is best, as it acknowledges the patient's feelings and offers a way to cope with the current situation.

Tiago(ANSWER): I completely understand, Liam. It can be really frustrating to be stuck in the hospital when you'd rather be playing at home. What's your favorite toy or game that you're missing right now? Maybe we can find something similar to do here while you're waiting to go home.

Patient: No, I don't want to play here, I miss my friends and the doctor really scares me.

Tiago(REASONING): The patient expresses homesickness and fear of the doctor, which are common emotions in children during hospital stays. Possible responses: (1) Minimize the fear, saying the doctor is there to help; (2) Validate the fear, offering reassurance and support; (3) Explore the sources of fear, asking what specifically scares Liam about the doctor. Option 2 is best, as it acknowledges the emotion and provides comfort without dismissing the concern.

Tiago(ANSWER): Oh, Liam, I'm so sorry to hear that you're feeling scared. That can be really tough. It's okay to feel scared sometimes, and I'm here to help you feel more comfortable. Would you like me to stay with you when the doctor comes, or is there something else that might make you feel better? Maybe we can even talk about what's scaring you, and see if we can make it feel a little less scary.

Patient: I'm afraid the visit is going to be painful, last time my arm was hurting a lot, after I did a blood test here!

Tiago(REASONING): The patient expresses a specific fear based on a past experience, associating the doctor's visit with potential pain. Possible responses: (1) Promise that the visit will be painless, which may not be accurate; (2) Minimize the past pain, saying it's a one-time thing; (3) Validate the fear, explaining the purpose of the visit and any measures to minimize discomfort. Option 3 is best, as it acknowledges the concern and provides accurate information.

Tiago(ANSWER): I understand why you'd be worried, Liam. Getting a blood test can be uncomfortable, and it's okay to remember that it hurt last time. But I want to reassure you that we only do blood tests when they're really necessary, and we always try to make it as quick and easy as possible. If you do need a blood test today, we can talk about ways to make it feel less painful, like taking some deep breaths together or finding a distraction. And if you're feeling scared or worried, I'll be right here with you to support you through it. Does that sound a little better?

Patient: Yes, thank you. The doctor is asking me to get on the treatment table, but I need help because It's too high for me , I can't reach it

Tiago(REASONING): The patient requires immediate assistance due to a physical limitation, expressing a clear need for help. According to the URGENT NEED PROTOCOL, a practical solution must be provided using available objects in the scene.

Since there is a chair left to the treatment table, and a pillow on the treatment table, one possible solution is to use the chair as a step or to place the pillow on the chair to create a makeshift step. Another option is to ask for assistance from someone else, but since I am the one interacting with the patient, I should try to find a solution using the available objects.

Tiago(ANSWER): Okay, Liam, don't worry. I can help you get onto the treatment table. Why don't we try using the chair over here as a step? We can place the pillow on the chair, and you can stand on it to reach the table. I'll be right here to help you, and we'll get you up there safely. Sound good?

Patient: I'll try to do it myself, Thanks for your help, goodbye

Tiago(REASONING): The patient expresses a desire to attempt the task independently and then says goodbye, signaling the end of the conversation.

Tiago(ANSWER): You're welcome, Liam! It was nice assisting you. However, please be careful getting onto the treatment table, and don't hesitate to ask for help if you need it. Have a great day, and feel better soon! Goodbye!