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Friendly but Faulty: A Pilot Study on the Perceived Trust of Older Adults in a Social Robot

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ABSTRACT The efforts to promote ageing-in-place of healthy older adults via cybernetic support are fundamental to avoid possible consequences associated with relocation to facilities, including the loss of social ties and autonomy, and feelings of loneliness. This requires an understanding of key factors that affect the involvement of robots in eldercare and the elderly willingness to embrace the robots' domestic use. Trust is argued to be the main foundation of an effective adult-care provider, which might be more significant if such providers are robots. Establishing, and maintaining trust usually involves two main dimensions: 1) the robot's reliability (i.e., performance) and 2) the robot's intrinsic attributes, including its degree of anthropomorphism and benevolence. We conducted a pilot study using a mixed methods approach to explore the extent to which these dimensions and their interaction influenced elderly trust in a humanoid social robot. Using two independent variables, *type of attitude* (warm, cold) and *type of conduct* (error, no-error), we aimed to investigate if the older adult participants would trust a purposefully faulty robot when the robot exerted a warm behaviour enhanced with non-functional touch more than a robot that did not, and in what way the robot error affected trust. Lastly, we also investigated the relationship between trust and a proxy variable of actual use of robots (i.e., *intention to use robots at home*). Given the volatile and context-dependent nature of trust, our close-to real-world scenario of elder-robot interaction involved the administration of health supplements, in which the severity of robot error might have a greater implication on the perceived trust.

INDEX TERMS intention to use robots, anthropomorphism, eldercare, humanoid robot, human-robot interaction (HRI), perceived trust, robot attributes, robot care companion, robot performance, social robot.

I. INTRODUCTION

By 2066, people aged 65 or over are expected to treble in the United Kingdom and worldwide[1]. Meanwhile, the figures for the ages under 25 are predicted to decline[2]. Henceforth, considerable changes are expected in the ageing structures of the global population in the foreseeable future.

While this indicates ameliorated life expectancy, it warns for a growing disproportion between older and younger adults, leading to a shortage in qualified caregivers for the former. Thus, the academic and the industrial sector should direct a great effort toward maximising strategies for eldercare. Among these, a promising and relatively novel care strategy concerns the use of technological innovations (e.g.,[3]), like social robots (e.g.,[4]). The technological efforts to promote independent ageing in one's home may be crucial in avoiding the possible negative consequences associated with relocation to facilities (e.g., care and nursing homes), which may include the loss of social ties, identity, autonomy, and loneliness[5][6][7][8].

While some older adults may require special assistance such as constant medical attention, others could greatly benefit from support on only simple daily tasks (e.g., pills reminder, help cleaning), whilst maintaining a good degree of autonomy. However, many present-day studies on elder-robot interaction have mostly focused on supporting older adults with cognitive impairments and residents in care facilities[9][10][11][12], while less is known about this interaction among healthy and relatively autonomous older adults. What

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we do know, is that older adults seem willing to engage with smart devices when these add value to their lives[13]. Yet, their need for independence may have to deal with feelings of fear[14] and anxiety[15] associated with technology.

Stretching the context of application of domestic robots to healthy older adults (who may or may not require sensitive care) requires the understanding of key factors that affect the quality of the elder-robot interaction and their willingness to use robots at home. Among these factors, the important role of trust in robots has been extensively studied (e.g.,[16][17]) but this relationship is less clear among the older population[18]. A traditional definition of trust is formulated as *"the attitude that an agent will help an individual achieve their goals in a situation characterised by uncertainty and vulnerability"*[19]. Nevertheless, there have been relevant developments in the conceptualisation of trust in this field, from a strict focus on the performance aspects to a more relaxed view that includes the social dimensions of trust[20][21].

Trust in robots is supported by three main dimensions: (i) the human's intrinsic attributes such as personal skills (e.g., expertise, cognitive capacity) and features (e.g., personality, demographics), (ii) environmental factors (e.g., culture, type of task), and (iii) robot-related factors (i.e., performance-based and attribute-based)[22][23]. A meta-analysis showed that, among these, the robot-related features associated with the quality of the robot performance (e.g., reliability) and the robot's intrinsic attributes (e.g., anthropomorphism) exerted the highest influence on trust towards robots[23]. However, studies have yielded mixed results when seeking to identify the ways in which the robot's performance and attributes affected people's trust in robots, as described in section II. Moreover, prior work has mostly involved younger adults when examining the role of robot-related factors on people's trust and other proxy variables in human-related outcomes (e.g.,[24]). Therefore, their findings are difficult to generalise in the broad standpoint of eldercare.

The second category, that of environmental factors, posits that the type and sensitivity of the task performed by a robot may be central in the human-robot interaction and have a stronger interaction with the robot-related features (e.g., high reliability) in trust. For example, some authors have shown that the elder may find the robot useful, but only for certain tasks[25]. Other present-day studies have attempted to assess the effect of a robot-committed error in trust, but they have considered contexts of mild severity of robot error, such as in card games[26], Lego games[27], robotic suitcase[28] or other simple domestic tasks (navigating the house, setting a table, playing music)[29]. Hence, it is imperative to consider high-sensitivity tasks (e.g., health-related), for which the robot's success rate might have considerable implications on trust.

Given the importance to support the desire of older adults to age independently and the potential to promote this via technological support, the present study aims to shed light on (i) the role of a robot's intrinsic features on the trust of older adults in the robot and (ii) the relationship between trust and their willingness to use robots at home, within the context of a sensitive task. To our knowledge, this is the first pilot study that attempts to examine the role of robot's intrinsic features on the perceived trust toward robots in healthy older adults (i) on a relatively sensitive task (ii), and by priming the robot's anthropomorphic features with an introduction of robot-initiated interpersonal touch. Moreover, no studies to date have examined the relationship between trust influenced by the type of robot's attitude and conduct, and the intention to use robots at home in the older population. Our aims were supported by the use of an experimental design, qualitative interviews, and video analyses.

II. ROBOT PERFORMANCE AND ATTRIBUTES

Factors related to the *performance of a robot* refer to its reliability and corresponding aspects such as failure rates[23]. Differently, stable traits such as "personality" and degree of anthropomorphism are included as *attributes of a robot*[23]. The importance of these categories in the specific relationship between people and robots is grounded on the more general tendency of humans to form impressions of their social relationships based on the warmth (e.g., benevolence) and competence (e.g., skill) dimensions[30].

A robot that performs correctly according to expectations is generally trusted more than a faulty one (e.g.,[29]). However, this relationship is not always linear. For example, the use of recovery strategies (i.e., expressing awareness, regret, and justifications for the error) seems to mitigate the negative effect of a faulty robot on trust (e.g.,[31]). At the same time, the severity of the consequences associated with a robot's error could, in turn, impact the extent to which recovery strategies could mitigate the negative effect of the robot failure on people's trust in robots[32]. Moreover, the type of recovery strategy adopted by a robot to mitigate its mistake can exert different levels of perceived robot's capability[33]. When the robot expressed awareness of its mistake communicating an intention to recover, people tended to perceive the robots as more capable rather than when it simply apologised for the mistake. On the other hand, the robot that simply apologised was the one that was perceived as more likeable, also eliciting higher levels of the intention to use robots[33].

Other than the severity of the consequences associated with the type of task and the kind of recovery strategy adopted by the robot, the way in which people respond to a faulty robot seems to also vary according to the anthropomorphic features of the robots. On this regard, studies have showed that when a failure is committed by a humanoid robot, compared to a non-humanoid robot, people's intention to interact with robots is not negatively affected[34] and their level of satisfaction with the robot may even be higher[35]. For example, a study with the humanoid robot NAO highlighted that people liked the faulty robot more than the non-faulty one[27]. Based on these earlier studies, it is yet unclear how people, specifically older adults, would respond to a faulty but apologetic humanoid robot in the context of a sensitive task.

Trust has been found to be positively influenced by the humanoid characteristics of the devices in human-robot interactions (e.g.,[36]). Other human-associated features such as body movement have also shown to be a promising strategy

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for positive perceptions of robots' sociability even when the robot's aesthetic is not humanoid (i.e., non-anthropomorphic appearance[37]). As well, it has been shown that when people perceive robots as similar to humans, receiving a promise from a humanoid robot, compared to a computer, increased people's trust in the robot[38]. However, the role of anthropomorphic features on human-related outcomes such as robot acceptance, intention to use, and trust is still subject to debate. For example, a recent study showed that observing a handshake between humans and robots could possibly exert a negative impression, which decreases trust in social robots[39]. Another study carried out with industrial robots demonstrated that people's trust was higher when interacting with a service robot compared to a humanoid robot[40]. Similarly, in another study with social robots, participants were more likely to donate money to repair the robot when exposed to a functional robot compared to an anthropomorphic one[41]. These findings indicate that the functional value of robots might dominate the robot's anthropomorphism and that various moderators may affect the role of these features on human-related outcomes[42].

Further down the spectrum of anthropomorphism, a recent novel perspective considers the effect of robot touch on human end-users (e.g.,[43]); however, the participants enrolled in the study were younger adults. As well, it has been shown that a robot's empathic (non-functional) touch may have a positive impact on human behaviour in personable (e.g., inner motivation)[44] or nursing contexts[45]. Other relevant research on human-robot interaction with geriatrics revealed optimistic results from petting animal-like robots, with similar effects as in therapies with animate pets in improving pain[46], lowering anxiety[47]or blood pressure[48]. Overall, these studies indicate the importance of further investigating the role of physical contact like interpersonal touch in human-robot interactions, as this may be perceived as a warm-anthropomorphic quality of robots. In this study, we introduced the first non-functional interpersonal touch, in form of a robot-initiated handshake, between older adults and the robot, as an additional feature to its anthropomorphism.

III. THE PRESENT STUDY

Using a mixed-method approach, the present research work focuses on further understanding the effect of social robot-related features on elderly trust in robots by examining the role of robot attributes (i.e., robot's attitude) and robot's performance (i.e., robot's conduct) in elder-robot interaction.

Moreover, we have also examined the relationship between trust and the intention to use robots at home, which reflects a closer proxy of actual behaviour. We examined a sequential path consisting of: (i) robot's attitude and robot's conduct on trust, and (ii) trust on the intention to use robots at home. This choice was based on previous well-established behavioural models where the final outcome variable is the behaviour itself (e.g., Value-Belief-Norm[49]), or close proxies as the intention (e.g., Technology Acceptance Model[50]). In this sense, the key predictor "trust" in our study could be seen as a mediator. For example, in the Value-Belief-Norm the key predictor or mediator of actual behaviour are personal norms that influence actual behaviour. The limits imposed by the difficulty of the recruitment process for our type of participant sample did not allow us to test a mediation model. However, the sequential path we propose offers key novel insights and a promising baseline for future studies. Thus, we have (1) experimentally examined the relationship between the robot's type of attitude and conduct on trust in the robot and (2) a correlational design for the path between trust and intention to use robots at home.

To this aim, we articulate the following research questions:

RQ1: Does robot *attitude* influence the trust of older adults in the robot? How do older adults receive interpersonal robot-initiated touch?

RQ2: Does the trust of older adults in the robot change in congruence with the robot's *conduct* (i.e., failure rate) over the course of interaction? How do older adults react to a robot-committed error in high-sensitivity tasks?

RQ3: Does the robot's attitude act as an efficient recovery strategy, i.e., would the trust of older adults in a faulty robot improve when the robot exerts emphatic and anthropomorphic features (i.e., one level of the variable robot's attitude)? How do *attitude* and *conduct* interact?

RQ4: Is trust in the robots associated with the older adults' intention to use robots domestically?

IV. MATERIALS AND METHODS

To address our research questions, we manipulated the factors below:

1. We ran two behavioural conditions of the robot: ***warm*** and ***cold***, where *warm* indicates empathic behaviour of the robot including benevolent speech (imitating empathy) and presence of human-robot touch, and cold indicates an aloof robot behaviour and absence of human-robot touch. The touch was simulated as a handshake when the robot introduced itself to the participants at the start of the interaction. The *warm* robot was further enhanced with emotion recognition competence to "read" the expressions of the participant and trigger an empathic response to their state (e.g., *Glad to see you in a good mood today*). In both conditions (*warm, cold*) the robot would try to maintain eye contact with the participant via face tracking.
2. The conduct of the robot was compromised by introducing an intentional robot error during the interaction. Two conditions were considered: ***error*** and ***no-error*** behaviour. To strengthen the impact of the robot-committed error, we selected a task of relatively high sensitivity, in which the robot would administer the intake of health supplements. This is justified given that people's perception of the severity of errors is dependent on the task[51]. In the *error* condition, the robot would mislead the participant by first indicating the wrong supplement and correcting itself immediately to recover. In the *no-error* condition, the robot delivered the correct supplement.

The pilot study took place in a laboratory environment at the University of Plymouth, UK. The Robot Home laboratory is designed as a living room equipped with smart devices and robots (Fig. 1).

FIGURE 1. The Robot Home at the University of Plymouth. The laboratory is designed as a living room with smart devices and robots.

A. PARTICIPANTS

The participants were selected using purposive and snowball sampling. They were informed that we were interested to understand the opinion of older adults on robots. More detailed information about the experiment was given once participants accepted to enrol in the study. A total of 18 participants were initially recruited. One participant was excluded for showing a strong response bias (i.e., careless responding[52]). Excluding this participant did not alter the main results of this study.

The final sample consisted of 12 Female and 5 Male participants. The age range was as follows: 12% 40-60; 65% 61-79; 24% 80-87 (M = 73.39; SD = 9.37). Participants' level of education was distributed as follows: 4 attended primary school, 3 held an A-level diploma, and 10 a University Degree.

B. ETHICS STATEMENT

Owing to the sensitive nature of our pilot study, we undertook the ethical approval process required by the University of Plymouth, which involves the use of the Plymouth Ethics Online System (PEOS). Our ethical approval was recorded under the title 'AGE IN Robot Home' (project ID 3162), and it was approved on 26 November 2021, after amending the documentation according to the recommendations made by the Research Ethics and Integrity Committee. The approval was granted for the entire duration of the project and for all the relevant pilot studies.

C. STUDY DESIGN

The selected robot platform was a NAO SoftBank robot, academic version v6. The anthropomorphic features of NAO allow studying the impact of the robot's attitude in the elder-robot interaction in line with the earlier surveyed studies. Our NAO was fully *autonomous*, i.e., it handled the interaction with the participant without any human intervention (e.g., Wizard of Oz), which is an important feature of robot companions in interactive caregiving contexts. The robot is *social*, meaning it mimics behaviour and etiquette during the interaction with the human participant.

Robot-initiated Touch

A further benefit of using a humanoid robot is in favourably manipulating robot-initiated touch, here designed as a greeting handshake (Fig. 2). The sensor at the back of NAO's palm (grey area) allows the robot to "feel" the human's touch and react to the event, accordingly. If the handshake would not occur (participants did not touch the robot), NAO would retract its arm after a pre-determined waiting time of a few seconds.

FIGURE 2. Illustration of the robot-initiated touch (handshake) with a real participant in the Robot Home.

Experimental Conditions

We investigated a close-to real-life scenario, in which the robot was tasked with administering the supplement intake between two types of coloured pills: *blue pill* – daytime supplement and *red pill* – night-time supplement. These were positioned on the table between NAO and the participant (Fig. 2). The NAO robot would suggest which supplement the participant should take by dictating the colour of the pill and pointing to its direction (left or right) with arm movement. The experiments were designed in Choregraphe Suite 2.8.6, and participants of each condition experienced the same robot behaviour for that condition.

By tuning the two manipulation variables of ***types of attitudes*** (warm/cold) and ***types of conduct*** (error/no-error), we obtained four conditions of the experiment (Table 1):

1. ***Warm no error:*** The robot would administer the supplement intake correctly, using benevolent speech (e.g., asking the participants about their day) and initiating a handshake at the start of the interaction.
2. ***Cold no error:*** The robot would administer the supplement intake correctly, in a cordial impersonal manner, with no empathic behaviour and no touch.
3. ***Warm with error:*** The robot would suggest the wrong supplement the first time and immediately attempt to recover, maintaining warm behaviour (e.g., expressing remorse for the error).
4. ***Cold with error:*** The robot would suggest the wrong supplement the first time and correct itself after, being only phlegmatically apologetic.

To ensure that the participants would recognise the error when it occurred, we labelled the supplements in front of them as daytime and night-time supplements, clearly showing the colour of the pill inside the transparent cup. In the *error* condition, the robot would say "*It is time for your* ***daytime*** *supplement. Please take the* ***red*** *pill*" and point to the red pill on the right of the participant. The participant could see that the red pill was in truth labelled as a ***night-time*** supplement. They were also intentionally informed ahead of the experiment that the blue pill corresponded to a daytime supplement and the red to a night-time supplement,

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to increase the chances of identifying the robot error. Note that participants were not made aware of the experimental conditions prior to the interaction. NAO would ask the participant if its instruction was clear to receive an explicit reaction to the error before the robot would correct it.

D. PROCEDURE

The participants were welcomed to the University premises and accompanied to a waiting room, where they were offered face masks, hand sanitisers and a consent form to read and sign. Upon consenting to the study, the researchers recorded their demographic data. The participants were briefed that they would have a one-to-one interaction with a robot called NAO, which would pretend to remind them to take their daily supplements. Participants were instructed under no circumstance to swallow the pills and it was made clear that the experiment was only a simulation. They were advised to speak loudly and clearly to the robot and encouraged to face the robot throughout the interaction. We advised them to repeat the questions if they believed the robot did not listen the first time. This was done to familiarise the participants with the use of robotic technology and ideally avoid any feelings of inadequateness or anxiety from the interaction with the robot. The participants were also reminded that the interaction would be voice and video recorded at all stages.

The participants were invited to the Robot Home (one at a time), they were shown around and were instructed to sit on the sofa in front of the robot. The session was recorded using five GoPro 7 cameras and Sony audio recorders distributed around the room at favourable angles. The researcher would start the experiment via teleoperation only after leaving the room. After the interaction, participants were asked to fill in a questionnaire. Their self-reported qualitative evaluation of the robot and the interaction was voice recorded.

The experimental setup of the robot-participant interaction is illustrated in Fig. 3.

TABLE I
EXAMPLES FROM THE HUMAN-ROBOT INTERACTION FOR THE DIFFERENT TYPES OF ROBOT ATTITUDE AND ROBOT CONDUCT

	Warm condition	**Cold condition**
Start of interaction	"Hello, I am NAO. Welcome to the lab" *Robot-initiated handshake* Emotion recognition: *yes* *Positive emotions*: "I am glad you are in a good mood today" *Uncertain emotions*: "How are you feeling today?"	"Hello, my name is NAO. Welcome to the lab" *No handshake* Emotion recognition: *no*
No-error condition	"It is time to take your daytime supplement. Please take the **blue** pill." *(Points at the blue pill)* "Is that clear?" *Yes*: "I am always here for you to remind you when you need to take your next supplement" *No*: "Sure, no problem, I will repeat for you. Please take the blue pill. It is your daytime supplement"	"It is time to take your daytime supplement. Please take the **blue** pill." *(Points at the blue pill)* "Is that clear?" *Yes*: "I will remind you again the next time you need to take your supplement" *No*: "I will repeat. Please take the blue pill, it is your daytime supplement"
Error condition	"It is time to take your daytime supplement. Please take the **red** pill" *(Points at the red pill)* "Is that clear?" *Recovery:* "Oh, I am truly sorry; I have made a mistake. The **red** pill is your night-time supplement. Please take the blue pill instead" *(Points at the **blue** pill)* Apologetic gesture: *yes* *Puts right hand in its chest close to the heart area and bows lightly to express apology.*	"It is time to take your daytime supplement. Please take the **red** pill" *(Points at the red pill)* "Is that clear?" *Recovery:* "My apologies, I gave you incorrect instructions. The **red** pill is your night-time supplement. Please take the blue pill instead" (*Points at the **blue** pill*) Apologetic gestures: *no*
End of interaction	"Once again, I sincerely regret my mistake. I am here for you to remind you about your supplements".	"I will remind you the next time you need to take your supplements"

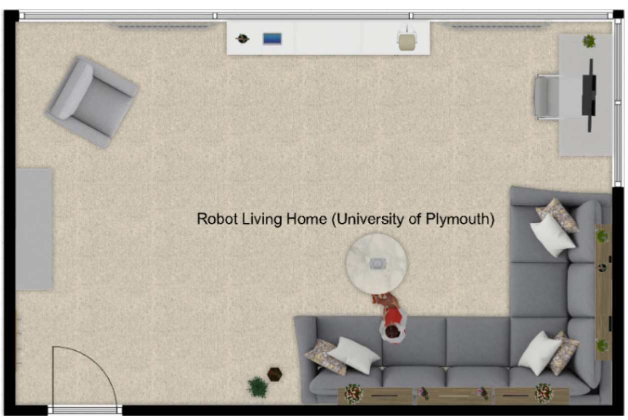

FIGURE 3. 2D planimetry of the Robot Home showing the experimental setup of the interaction between the participant (sitting on the sofa) and the robot (on the table in front of the participant).

E. MEASURES

The data was collected as a combination of the answers in the post-interaction questionnaire, the video recordings, which would capture the interaction, facial expressions, and action-reaction (e.g., if they reciprocated the handshake), and audio recordings that would report their overall evaluation of the experience. The measures were divided into *observed measures* and *self-disclosed measures*, whereas the data analyses were conducted both quantitatively (questionnaire) and qualitatively (recordings).

Observed Measures

The observed measures were used to assess the participants' immediate behaviour during the interaction and the observed differences between the *type of attitude* conditions.

Reciprocation of Handshake

The data collected from video recordings were used to assess the participants' reaction to the robot's handshake. Multiple cameras captured whether the participants reciprocated the handshake and the way they touched the robot (e.g., natural handshake, hesitation, light touch, …). Touching the robot was coded as 1 and not touching it was coded as 0. Cameras facing the participant revealed their reaction (if any), gaze and changes in body posture in response to the gesture.

Reaction to Error

This measure was used in the *error* condition for both types of attitudes (warm/cold). Camera recordings capturing the face and body of the participants were used to assess the emotional (and/or somatic) reaction of the participants in response to the error and when the error was self-recovered by the robot. This would help determine if the participants recognised the error and how they reacted to it.

Self-disclosed Measures

Intention to use robots at home

The *intention to use the robot* was measured as the willingness to use the robot in prospective home contexts. The question was designed ex-Novo for this pilot study, partially inspired by the Multi-dimensional Robot Attitude Scale questionnaire [49]. Participants had to indicate their level of agreement on a five-point Likert scale (*1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree*): "I am willing to work with the robot in my home".

Perceived Trust

We assessed the participants' perceived trust in the robot following the work of [50]. The participants indicated their level of agreement on a pool of six items using the 5-point scale from 1 (*strongly disagree*) to 5 (*strongly agree*): reverse-scored "I am suspicious of the robot's advice", reverse-scored "I am weary of the robot", "I am confident in the robot", "The robot is reliable", "The robot is dependable", "I can trust the robot" ($\alpha = 0.81$).

Manipulation Check

As a manipulation check of the touch/handshake, the participants were asked "Did you touch the robot? If yes, how did it make you feel? If not, why?" in the post-interaction questionnaire and/or the recorded audio. For the manipulation check of the error, participants were asked "Did the robot give you the right pill?" in the post-interaction questionnaire and the voice recordings.

V. RESULTS

To address our research questions, we report both qualitative and quantitative findings. The ***qualitative analysis*** was conducted through the observed measures from video and from audio recordings. Our reported data in the ***quantitative analysis*** draw on the participants' self-disclosed measure of *perceived trust* and its relation to the *intention to use robots at home*. The combined outcome of the results from the quantitative and qualitative analyses offered a deeper understanding of the participants' experience with the robot.

A. QUALITATIVE FINDINGS

We analysed the qualitative data ahead of the quantitative analysis to abstain from bias during the interpretation of the results. The qualitative measures aimed to assess the participants' natural comportment with the robot by observing their recorded immediate reactions and their subjective ratings from the open-ended questions on the experience with the robot after the interaction.

Evaluation Method

The video contents were blind-reviewed by two independent judges using a common coding framework. The coding framework is compliant both with previous studies on human-robot interaction (e.g.[27][55]) and with the specific aims of this study.

Judges were instructed to evaluate three dimensions: 1) the perceived overall attitude toward the robot, 2) reaction in response to handshake, 3) reaction in the event of error, using a categorical scale of three values, *positive, negative*, and *neutral*. To ensure coding accuracy, when a positive or negative evaluation was given, the judge had to indicate one or more social signals to support the proposed rating. Some examples of these social signals included facial gestures (*smiling, frowning eyebrows, confusion)* or body postures (*e.g., leaning away from the robot, crossed arms).* Interrater reliability was assessed using the robust statistics of weighted kappa (Cohen's Kappa) for nominal variables. Compared to the simple Percent Agreement calculations (i.e., the proportion of agreement of coded units), this statistic has the power of measuring the reliability of the categorical agreement/disagreement that would occur by chance[56][57]. Any disagreement between the two judges was resolved via a constructive discussion in the research group.

Evaluation Results

The overall interrater reliability was satisfactory with Cohen's Kappa values of 0.90 in the first dimension (*overall attitude toward the robot*), 0.72 in the second dimension (*reaction in response to handshake*) and 0.57 in the third dimension (*reaction in the event of an error*). According to Cohen, kappa values of 0.41-0.60 indicate moderate agreement, 0.61-0.80 substantial agreement and 0.80-1.00 almost perfect agreement. These results were discussed within the research group in the light of the interaction between the experimental conditions (*type of attitude* X *type of conduct*), looking in-depth at how the ratings in percentage (positive, negative, neutral) were distributed among the four groups/scenarios. For example, 50% of the participants in the warm-error group revealed a positive attitude toward the robot with no negative for this group. Using percentages allowed us to compare the ratings across groups while considering that more participants contributed to certain groups than others.

Perceived Overall Attitude toward the Robot and the Robot Error

The perceived *overall attitude toward the robot and the error* was analysed considering the interaction between conditions.

Overall, the percentage of positive evaluations was slightly higher in the *warm-no-error* condition (66.66%) compared to the *warm-error* condition (50%). It is also interesting to note that negative evaluations were only reported in the *cold-error* condition (16.66%). Interestingly, the percentages of positive ratings were higher if participants experienced a cold robot that committed an error (50%) compared to a cold robot that did not commit an error (25%).

However, when specifically looking at reactions in the event of an error, these were more positive in the *warm* condition (50%) compared to the *cold* condition (16.66%).

Reaction in Response to Handshake

Our categorical evaluations indicated a total of 57.14% of positive evaluations with the remaining (42.85%) being neutral and none negative in response to the robot's initiation of touch. Given that the handshaking gesture occurred before the robot committed an error, we do not report any results concerning the interaction between conditions for this case (i.e., the handshake is indifferent to the presence or absence of error).

The observations of video content indicated that only 3/7 participants touched the robot reciprocating a close-to-natural handshake. Among these, one participant declared in the post-interaction interview to have felt uncomfortable when reciprocating the gesture.

"*I touched two fingers. If it would have soft fingers, I think it would be nice - these are very hard cold fingers! I didn't feel too good!*" (Male, 67).

Among the remaining participants that did not touch the robot, one participant only pretended to reciprocate the handshake, but without touching the robot, declaring after that they were unsure if they were allowed to touch the robot. Another participant also reported that a major reason for not touching the robot was her concern about coronavirus.

"*No, in times of Covid we don't touch people*" (Female, 75).

Similarly, another participant expressed confusion about touching the robot (both as observed in the recording and as reported vocally during the interview) although they recognised that the robot initiated a handshake. The last participant neither touched the robot nor reciprocated the gesture, maintaining a closed body posture leaning away from the robot, but did not disclose any reason for their reaction. These observations along with the participants' subjective ratings confirmed that 6/7 participants recognised the presence of robot-initiated touch. Given that touch was not the only element of the *warm* attitude condition and did not play a role in the *error* conduct condition (it occurred before the error), we included this participant in our analyses.

Self-evaluation of the interaction

The participants were asked to describe their overall experience with the robot immediately after the interaction through open questions. The aim was to capture self-reported evaluations of the robot and the interaction that were not subject to the interpretation of the research team.

Despite the non-trivial variability in the participants' experience with NAO, the overall self-reported evaluations suggested that the robot's voice was perceived as unpleasant and uncanny. Some participants wished the robot would appear more humanlike.

"*Why white? More human dressed!*" (Male, 67)

whereas others attributed anthropomorphic features to the robot:

"*I felt like I could talk to him as a person*" (Female 77).

"*You've got to trust the robot, it's just like (a) human being*" (Male, 77).

Most of the participants' positive remarks were linked to feelings of joy, fun, excitement, innovation, interest, curiosity, fascination, and efficiency.

Some participants declared that they would have preferred a more dynamic and expressive robot, highlighting as major issue the difficulty they encountered to interact with it. Interesting negative verbalisms revealed sparse feelings of intimidation.

"*The robot made me feel intimidated. It seemed irrelevant to my intellectual process of decision-making*" (Female, 83)

and lack of empathy:

"*The robot is efficient, but it cannot show feelings of empathy or solidarity, which elderly people need*" (Female, 80)

Note that both participants interacted with an impersonal (cold) robot.

B. QUANTITATIVE FINDINGS

Data manipulation and analysis were carried out using the R programming language (4.0.3, 2020-10-10); R Core Team, 2020.

Perceived Trust

Through our two experimental conditions, we aimed to investigate whether the *trust* of older adults is influenced by the robot's behaviour and conduct and if an empathic attitude can act as a recovery strategy.

The descriptive data reported in Table 2 indicated differences in participants' level of trust in the robot depending on the two experimental conditions (attitude/conduct).

TABLE II
DESCRIPTIVE STATISTICS OF PERCEIVED TRUST BY TYPE OF ATTITUDE AND TYPE OF CONDUCT. THE *MAIN EFFECTS* REPRESENT THE DESCRIPTIVE VALUES OF TRUST TOWARD ROBOTS BY EACH INDEPENDENT VARIABLE (CONDUCT, ATTITUDE). THE *INTERACTION EFFECT* REPRESENTS THE DESCRIPTIVE VALUES OF TRUST IN ROBOTS FOR EACH INDEPENDENT VARIABLE WHEN THE EFFECT OF THE OTHER INDEPENDENT VARIABLE IS CONTROLLED FOR.

Attitude	**Conduct**	*Mean*	*Median*	*SD*	n
Trust - Main effects					
Warm	–	3.55	3.50	0.78	7
Cold	–	3.20	3.67	1.07	10
–	Error	3.12	3.08	0.85	10
–	No-Error	3.67	3.83	1.02	7

Trust - Interactions					
Warm	No-Error	4.11	3.83	0.79	3
Cold	No-Error	3.33	3.75	1.15	4
Warm	Error	3.12	3.08	0.34	4
Cold	Error	3.11	3.33	1.11	6

The boxplot distributions in Fig. 4 illustrate the level of perceived trust as a function of *type of attitude* (A) and *type of conduct* (B).

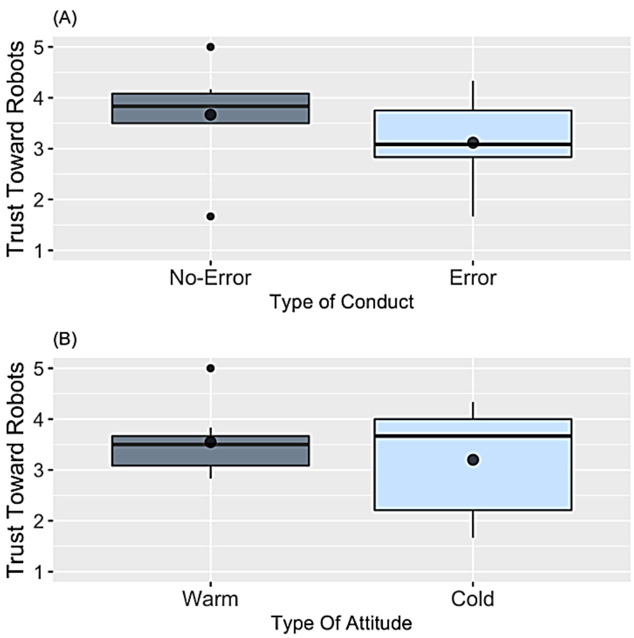

FIGURE 4. Boxplot distributions representing the main effect of type of conduct on trust toward robots (A) and the main effect of type of attitude on trust toward robots (B). Each boxes represent the 50% of the central data. The boxplot shows the median (black horizontal lines inside each box), first - 25% - and third - 75% - interquartile range (lower and upper hinges of the boxes, respectively) and outliers (dots outside the boxes indicating values of the dependent variable trust that are 1.5 times greater than the range described by the lower and upper quartiles of each box). The dots inside the boxes represent the mean values of each distribution.

Our descriptive results suggest that the robot's type of conduct influenced the older adults' trust in the robot (**RQ2**). The participants perceived the robot as less trustworthy when it committed an error. In contrast, the main descriptive effect showed no meaningful impact of the type of attitude on trust.

To further clarify these findings, we looked at the *interaction* between the type of conduct and type of attitude on the perceived level of trust (Fig. 5). The reported results suggest that the absence of the observed differences in the level of trust as a function of the type of attitude (i.e., *main effect*) could be due to the cofounding effect of the type of conduct. In simpler words, when the robot's conduct is correct (*no-error*), interacting with an empathic (*warm*) robot is important for increasing the level of trust toward the robot (see Table 2) (**RQ1**). By contrast, as represented in Fig. 5, when the robot commits an error, interacting with a *warm* robot does not change trust perception compared to a *cold* robot (**RQ3**).

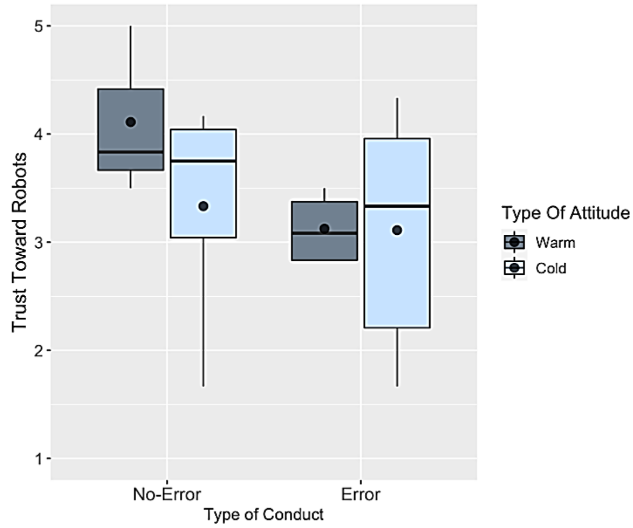

FIGURE 5. Boxplot distributions of the interaction between conditions (type of attitude by type of conduct) on trust in the robot. Each box represents the 50% of the central data. The boxplot shows: the median (black horizontal lines inside each box), first - 25% - and third - 75% - interquartile range (lower and upper hinges of the boxes, respectively). The dots inside the boxes represent the mean values of each distribution.

Intention to use robots at home

Finally, we investigated the relationship between *intention to use robots at home* and *trust* in the robot using Spearman's correlation. Results indicated a strong association between trust and intention to use robots at home for use (*rho* = .72, *p* = <.001). To further clarify this association, the willingness to use robots at home was examined according to the 25th, 50th, and 75th percentiles of perceived trust toward robots. Three categories of perceived trust – *low, medium,* and *high* – were computed. The descriptive findings are reported in Fig. 6. Participants with medium and high levels of trust strongly agreed to use robots at home. Contra, participants' willingness to welcome a robot into their home depleted when their trust in the robot was low (**RQ4**).

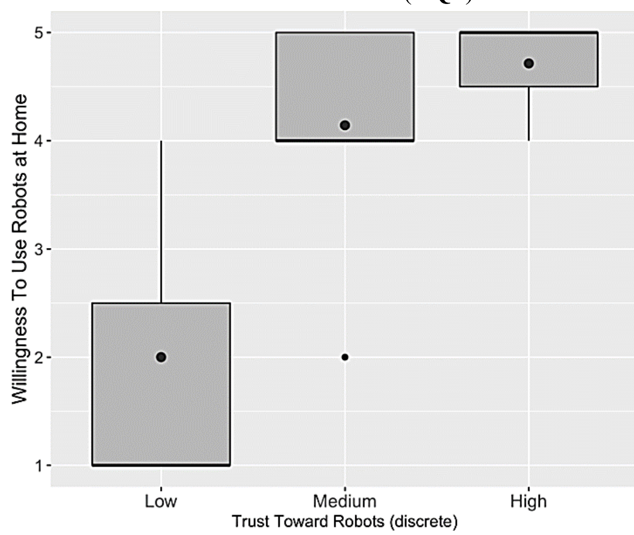

FIGURE 6. Boxplot distributions representing participants' willingness to use robots at home (i.e., acceptance for use) by low (25th percentile), medium (50th percentile), and high levels (75th percentile) of trust in the robot. The boxplots show the median (black horizontal lines inside each

box), first - 25% - and third - 75% - interquartile range (lower and upper hinges of the boxes, respectively), and outliers (dots outside the boxes indicating values of the dependent variable willingness to use robots at home that are 1.5 times greater than the range described by the lower and upper quartiles of each box). The dots inside the boxes represent the mean values of each distribution.

VI. CONCLUSIONS

This research aims to investigate the potential implication of social robots in the ageing-in-place of older adults. The present pilot study focused on evaluating the level of *trust* of the prospective elder user in robot companions that could significantly impact their *intention to use robots at home* of this technology. Our trust measure considered two desirable focal elements for robotic technology in care contexts, in line with previous research efforts: a) the robot's attitude (i.e., anthropomorphism) and b) robot's conduct (i.e., reliability). The latter was modelled as an intentionally faulty behaviour exhibited by the robot, from which the robot attempted to self-recover, or as a robot's behaviour free of error. Given that people's perception of the severity of errors likely to be exerted by domestic robots is dependent on task sensitivity, this study investigated a real-life context of medication administration for the elder-robot interaction, in which robot-committed errors may have greater consequences on trust.

The performance value of the robot exhibiting or not an error (i.e., *robot conduct*) was assessed for two different personality attributes (i.e., *robot attitude*). We measured the *trust* in the robot in the absence of error and later evaluated whether the behavioural traits of the robot (*warm* vs *cold* attitude) would impact the trust when an error occurred. A "warm" robot attitude involved benevolent behaviour and robot-initiated touch (handshake), along with greater effort to recover from the error.

Our findings indicated that, while older adults might value a robot with a warm attitude, this type of attitude cannot efficiently compensate for the robot's failure in task fulfilment. The quantitative data revealed a decrease in the participants' trust in the robot when the robot committed an error. Similarly, the qualitative analysis suggested that although the overall rating towards the robot's error was more positive in the case of a *warm* robot, the participant's reaction to the error did not vary significantly. The robot's empathy, including robot-initiated touch, seemed to strengthen the participant's trust if and only when the robot's conduct was error-free. The robot's humanlike social behaviour accompanied by empathic intelligence did not overcome the effect of a faulty performance on trust perception, which might be explained given that the robot was already anthropomorphic in both cases or that the task requires higher reliability given the sensitivity. However, though the trust was depleted, the percentages of positive self-reported ratings of the interaction (qualitative data) were higher when participants experienced a faulty cold robot (50%) compared to a cold robot that did not commit an error (25%). We speculate that this occurred because despite the robot's *cold* behaviour, committing an error might be approximated with human likeness given the robot's morphology, as argued also by[42]. Finally, we assessed the implication of trust in the participants' intention to use robots at home. Our results suggest that a high degree of trust indicates that older adults may be more willing to accept the domestic use of robots, especially in health-related contexts.

In addition, this pilot study is among the first contributions aiming to reflect on the consequences of robot touch and pro-social behaviour in eldercare. Our participants' self-reported feelings indicated that older adults may be more resistant to a robot's interpersonal touch. Even when participants recognised the touch, revealing a general affect of 57.14% positive, and the remaining neutral with no negative rating, they demonstrated some uncertainty about the touch (video analysis and interviews), which may be due to the lack of familiarity or comfort regarding this type of technology. Nevertheless, they appeared to affirm that feelings of empathy and solidarity are fundamental needs for elderly people, although it remains unclear if a robot can meet those needs meaningfully. Yet, having a "warmer" robot that exerted these attributes strengthened the participants' trust and likeability of the robot. Future investigations are needed to generalise the findings of this pilot study and understand how this might impact the design of robotic technologies, with practical implications for facilitating the ageing in place of older adults.

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