Towards Human-Based Models of Behaviour in Social Robots: Exploring Age-Related Differences in the Processing of Gaze Cues in Human-Robot Interaction

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Abstract

The emergence of robotic systems offers many opportunities for older adults (OA) to support their daily life activities. Therefore, there is a need to study social interactions between OA and robots better. One important aspect of social communication is the use of non-verbal cues, of which eye gaze has proven to be of special interest both in the fields of social cognition and HRI. In this paper, we review previous work on HRI with OA and propose an experiment to compare the influence of gaze behaviour of robots on older and younger users. These findings will allow a better design and adaptation of social robots to age-related changes in aspects of social cognition.

1 Introduction

In most developed countries, population ageing is confluent with the fourth industrial revolution. The emergence of robotic systems offers many opportunities for older adults (OA), a group that will represent a 16% of the total population by the year 2050 [Uni19]. Usually, robots for OA have been developed to assist on more severe age-related issues, such as mild to high cognitive impairment [TFM08], or to support negative emotions like loneliness [HLB+11]. However, robots can also improve the quality of life in everyday tasks for the whole OA population irrespective of their health or emotional conditions. The emphasis on robots as a “solution” for ageing can give rise to stereotypes of later adulthood and can also displace the focus from possible interaction issues for OA, regardless of what a particular technology has to offer. This perspective could present problems in the acceptability of robots, for example, in the form of a false perception of companionship or an exaggerated sociability [DEP+19].

OA could benefit from the use of robots in a similar way than any other person could do. A robot designed to help in everyday tasks such as cooking or cleaning might be appealing to users irrespective of their age range. However, there are changes at the cognitive level through human lifespan that could modulate the preferences of interaction with robotic systems [FPES+18]. While complex interfaces could heighten the ease of use for OA, multimodal and natural interactions are perceived as more intuitive for everybody [KRW+19]. Social robots, devices with more social competence such as speaking or using non-verbal cues may reduce, or even eliminate, the learning curve for the OA. It also has been shown that this use of non-verbal cues can enhance the feeling of

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engagement with robots and can facilitate the interaction with them if robots are designed considering human traits of social cognition and communication [AMT15].

There is, however, little theory-driven research that has actively searched for principles of interaction between robots and OA based on principles of human communication and social cognition. The emphasis has been frequently placed in the validation of systems designed for senior users and for very specific functions. Human-Robot interaction (HRI) studies with OA often report usability and acceptance scores of a system, but do not emphasise the creation of models of interaction. These could be based on theory-driven studies of HRI, but in order to investigate if previous findings apply to OA, they should to be tested with different groups of age and under the same circumstances (type of tasks, measures, etc). This is reflected in the review performed by [ZN19], where the authors noticed that control groups of young participants are often missing in the literature of HRI for OA. These young control groups may be useful to create models of interaction that consider the development of the cognitive profile of users as they age.

Studies in HRI have shown that non-verbal communicative patterns similar to the ones used in human-human interactions are perceived as social when used by a robot [KPA+19][Żar19]. One outstanding example of non-verbal communication is eye gaze, a powerful social cue able to convey many different messages multiple depending on the context [CH19]. Eye gaze behaviours from the robot have also been studied and described as interaction facilitators during HRI [ZBK17], but despite the evidence of age-related differences in the attentional response towards social stimuli [SPB08][KPMB15][FMOC20], we did not find previous studies that explore the existence of age-related differences in the processing of gaze cues from a robot during the interaction process.

Therefore, in this paper we present a multidisciplinary apporoach approach to ageing and HRI and propose an experiment based on it. Our objective is to study the influence of eye gaze behaviour of robots over older and younger participants. The main aim is to study whether there are differences in the way OA process social cues during an interaction with a robot in comparison with younger persons, and whether the changes in social cognition during the later stages of life apply to the context of HRI. This paper presents work in progress, as we just designed the basis for our experiment and we are currently in the stage of recruiting participants. Thus, we present a theoretical framework and a proof of concept based on previous work, but cannot present empirical results at this stage.

The rest of this paper is organised as follows. Section 2 introduces studies related to interactions between social robots and OA, as well as some principles of human communication and social cognition in the context of HRI. In addition, we present the Interpersonal Gaze Processing Model [CH19] and studies in cognitive science that have explored the evolution of social and gaze processing through the lifespan, as they will become the base for our research. Section 3 discusses the importance of an integrated framework between gerontology, robotics and cognitive psychology for studying HRI for OA. We also propose an experiment to explore potential differences in how the gaze of a social robot is processed between younger and older users, which is built on previous studies by [KPA+19] and [MT18]. Finally, in section 4 we describe the experimental setup and methods that we will use.

2 Previous Studies

There is evidence of users' preference for robots that show certain human features. It has been shown that anthropomorphic robots enhance the social presence of a system [KPA+19]. Social presence, related with the attribution of awareness somebody gives to a system [HB04], increases the acceptability of both older and younger users [FPES+18]. Nevertheless, the attribute of social presence over a robot that features a human-like shape and behaviour is mediated by a top-down attentional bias towards social stimuli in humans that varies in normal ageing [FMOC20]. However, these differences have not been tested in interactions with robots. Despite our tendency towards social features, just a few studies covering HRI that explore aspects of social cognition in humans and the possible differential outcomes in OA [FM15] [FPES+18].

In spite of the attentional bias towards social stimuli, social robots do not necessarily need to fully look and behave like humans. While this could increase their social presence, the levels of acceptability could drop. The work in [MMF+16] found that although anthropomorphic shapes were preferred among other designs, there was no need for realistic interfaces that try to imitate humans in all their forms as OA would feel uncomfortable to interact with them.

In order to understand which aspects of social cognition might promote acceptance and social presence, these should be studied in isolation and under controlled conditions, even before developing a functional robot and its validation. This can be done using a "Wizard of Oz" (WoZ) design [Rie12], an approach in which the robot is controlled by a human agent without the participants being aware of it. The benefits of its use include the avoidance of having to develop a prototype that might not be fully reliable, and thus, negatively affect the interaction. This approach has been used in a study where the effects of embodied anthropomorphic robots were investigated between two groups of older and younger participants [FPES+18]. Despite the preference for humanoid robots in both groups, OA preferred to interact by touching the hand of the robot rather than using a tablet attached to the system, which was the preferred way of interaction for the younger group. Even though the reasons for these differences in preference of interaction are not clear, this study is the first addressing differences in the way two groups of age interact with an anthropomorphic physical robot.

The effects of robots that feature non-verbal communication cues have been widely studied and have generally reported high acceptability and social presence. Crompton and MacPherson [CM19] reported an increase in accuracy and decrease in completion time for a collaborative task with a non-embodied agent when it used a natural human voice and the OA thought of the system as a human person. However, we could not find more studies that have focused in non-verbal interaction communication between social robots and OA. Nevertheless, it has also been shown that robots that use personality matching through gaze increase the motivation of the user to engage in a repetitive task [AMT15]. In a later study it was also shown that gestures and speech based on the personality of the user are preferred when compared to robots that just express the personality match through speech [AT16]. In spite of not studying interactions with OA, these experiments explore interactions with social robots based on individual differences of personality traits (introversion-extroversion, from the Big-five model of personality [Gol99]), which has been shown to vary through the human lifespan towards lower extraversion attributes during adulthood [CHMS00]. The results of these studies do not just highlight the importance of non-verbal communication for designing better HRIs, but also the importance of multimodal communication in [AT16]. They are also examples of how human-human interaction principles (Similarity-Atraction principle [BHHB84]) and psychological models [Gol99] can be applied to HRI.

After [AMT15], eye gaze behaviour has also been implemented in robots by using psychological principles, and generally favourable results [KPA+19, Żar19]. In parallel to these implementations, psychological models related with how humans respond to eye gaze have rapidly evolved thanks to the development of new research tools and a new focus on real interactions beyond lab settings [RK17, MT18]. The nature of eyes is dual: while our eyes allow us to gather information about the world, they also send non-verbal signals that can convey multiple meanings. By looking or not at others, we may be trying to seek or avoid their attention if not engaged in an interaction [CH19]. However, even if already engaged in an interaction, we tend to look less to a collaborator than to a picture or video of a person, challenging traditional findings suggesting our visual bias towards social stimuli in every circumstance [MT18]. The Interpersonal Gaze Processing model [CH19] examines the planning of eye movements depending on if the social stimulus is a real live person or not (a picture or a video for example). According to this model, our gaze behaviour depends heavily on the belief of being seen. Despite our preference for social stimuli, during a real interaction our gaze is also driven by the communicative purpose we want to convey, gaze direction of the other (which determines if our gaze is perceived by the other or not) and coordination with his or her social signals (for turn taking, for example).

Previous research has found age-related differences in some aspects of social perception. It has been shown that there is a decline in the detection of gaze and the ability to engage in joint attention [Tom95] in normal ageing [SPB08] as well as declines in gaze following [KPMB15]. However, there is recent evidence that some aspects of social cognition are especially resistant to the effects of ageing. [LBG+19] showed that an effect of likeability towards photographs featuring faces oriented towards the observer is preserved in OA. In addition, it has been suggested that affective Theory of Mind, an important aspect of social cognition by which humans and some primates make inferences about other emotional internal states [PW78], is independent of executive function, as it is also preserved in OA and does not decline with age [YSG20]. To conclude, there is evidence that some aspects of attention are preserved in normal ageing when tested with social stimuli, and what is more, that OA exhibit an increased biased towards human faces than younger [FMOC20]. It must be noted that none of the studies in ageing that we just mentioned were done in contexts of real interactions.

Investigating social dynamics in a laboratory context without real humans as stimuli (that means pictures, drawings or movies) does not allow the generalisation of findings for everyday life. This explains the importance of the Interpersonal Gaze Processing model [CH19], as well as the increased interest in the last few years for naturalistic studies that investigate visual dynamics during social interactions [RK17]. This renovated interest in social interactions and the influence of eye gaze has also been translated to the field of HRI. There are other examples of robots that follow human gaze principles. Zhang et al. [ZBK17] reported that their model of mutual gaze behaviour, which responds in real time to users' gaze, improves the engagement between the robot and the user. It has also been shown that robots that take into account turn-taking social norms during an interaction with multiple users leaded to less conversational errors, more communicative performance and better perception of the robot being communicative (social presence) [Żar19]. In contrast with previous literature, the preferences for robots that feature human-based gaze behaviours are not always linked with a better performance. [KPA+19] performed an experiment that consisted on a collaborative cooking task in which a robot had the role of instructor and participants followed instructions by gathering ingredients and preparing the meal. Results showed that task performance decreased as an effect of the anthropomorphism and the gaze behaviour the robot featured, based on turn taking and joint attention behaviours. The contrast of this study with previous literature might imply that despite the increase of social presence these features evoke, the benefit of task performance might be task-specific. Building on this study, we suggest an experiment consisting on an interaction with a robot with two groups of younger and older participants.

3 The Importance of Eye Gaze in HRI

There is a need for research that investigates how age-related differences in the processing of social cues, especially eye gaze, might translate to interactions with social robots. We consider that an approach that combines studies in ageing, cognitive psychology and robotics is necessary in order to design human-centred models of AI behaviour and robots. Based on this and in the work of [KPA+19], in this paper we suggest an experiment with the main objective of investigating age-related differences of gaze behaviour processing during an interaction with a robot in a task consisting on preparing a meal with the help of the robot. Preparing food and cooking are everyday tasks that are suitable for most of the people and constitute a realistic interactive scenario that has also been previously studied in human-human collaborative tasks [RK17, MT18]. In addition, we also choose this task to replicate the findings of [KPA+19], which suggest a trade-off between perceived sociability and task efficiency in the way they set this interaction. This trade-off could be more pronounced for OA, as it has been shown that despite of a preference towards pictures showing direct gaze [LBG+19] and anthropomorphic robots [FPES+18], there is a decline in shared gaze processes in OA [SPB08, KPMB15]. This decline could slow down the speed at which they find the ingredients, and potentially, the completion time of the task.

With this experiment, we aim to contribute to the understanding of how different social cues are perceived as an effect of ageing in the context of HRI. Additionally, we also believe that this study might have implications in understanding how age-related differences in visual attention towards social cues occur during a real social interaction between humans, where both parties see each other, in a naturalistic context. We also find of interest to explore the "feeling of being seen" on which [CH19] built the Interpersonal Gaze Processing model in the presence of a robot.

4 Experimental Setup

In order to assess the difference in impact of social eye gaze in robots on older and younger participants, we will use a social robot and a human agent. Both agents will use the same dialog patterns and will instruct and help participants in a task consisting on preparing food.

Forty participants are expected to take part in this study, twenty per group of age. Both older and younger participants will be recruited in the Örebro region with the assistance of the university Successful Ageing Research School[1]. For this study, OA over 65 years old who are living at home and with a normal cognitive profile will be recruited. We have chosen this age limit since most studies in HRI and OA have used values around this age [ZN19], which is consistent with the definition of OA given by the United Nations [Uni19]. The age limit for younger participants will be set on 35 years old, since we consider that a minimum difference of 30 years is wide enough for detecting potential differences between groups of age. In order to increase the motivation during the testing period, participants will take home the food they prepared during the task. We will aim to reach a similar variability between groups in the scores of other potentially confounding variables that could be plausible causes for differences between groups in the dependent measures scores by keeping them constant. These plausible alternative covariates are: *experience with new technologies* and *interest in new technologies.* Three subgroups will be created per group of age in order to counterbalance the order presentation to avoid fatigue and learning effects [Cor17].

A human actor or a social robot[2] (Figure 1) controlled by a human agent (Wizard of Oz) will play the role of instructor depending on the condition. The participant will sit in front of a table where a set of different

[1] https://www.oru.se/english/strategic-initiatives/successful-ageing/
[2] Pepper, from Softbank Robotics: https://www.softbankrobotics.com/

ingredients will be placed. The participant may also use some kitchen utilities such as a cutting table, a knife, a spoon and tongs for taking the ingredients.

Participants' eye-movements will be recorded using a Pupil Eye-Tracker[3], which allow for free head movement. The eye-tracker consist on three cameras: The world camera records the user perspective at 30Hz, while the other cameras will record each eye at 120Hz each with spatial accuracy of about 1°. Before each condition, we will perform a manual 9-point calibration over different depths of the table where the task will be performed, as recommended by the manufacturer when working in midrange distances (1-2 metres) and with a wide field of view.

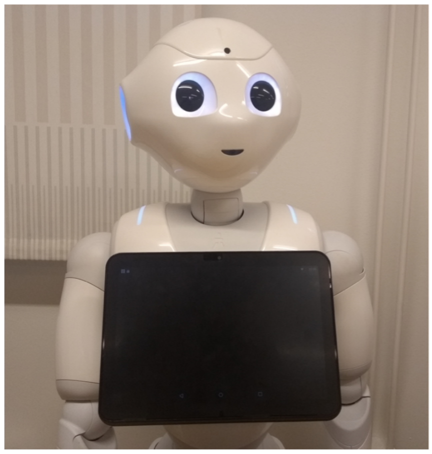

Figure 1: On the left, a picture of the experimental setup during an interaction. The participant takes an ingredient following the instructions of the agent. On the right, the Pepper robot used for this study.

Participants will be asked to prepare three different types of sandwiches without knowing the ingredients and with the help of the robot or the human agent. The recipes will be similar in terms of preparation difficulty. Participants will interact with the agent and gather the required ingredients for the preparation of a specific sandwich. The role of the agent will be to instruct them after each step and guide them when they have doubts about the location of an ingredient. The gaze behaviour of the robot will be aimed to initiate joint attention with the participant as well as to indicate turn-taking[4]. The task, dialogue policy, and gaze behaviour of the robot are based on [KPA+19].

This study will follow a 2 X 3 Mixed Design [Fie18]. Two groups of age, older **(O)** or younger **(Y)** (between-subjects), will perform the same set of collaborative tasks with the robots. Every participant of each group will interact in a collaborative task under three different conditions that define the agent participants will interact with (within-subjects):

1. Human **(H)**: A human instructor will guide the participant through the task.

2. Robot **(R)**: A robot will guide the participant through the task, but without featuring any behaviour beyond verbal instructions.

3. Social Robot **(SR)**: The same robot (R) will guide the participant again, but this time it will feature eye gaze behaviour in the form of head movements. These will be aimed to initiate joint attention with the participant and to indicate turn-taking.

Eye-tracking gaze behaviour from each participant will be annotated for analysis. The first two measures we will investigate are related with task efficiency. These are (1) *task completion time* and (2) *time for joint attention*, which consists on the difference in time since the agent first orientates towards an ingredient and the participant first fixates it, which is the moment participants first maintain their gaze on the ingredient. The third and fourth measures will be related with social presence. They are (3) *proportion of time looking at the agent* and (4)

[3]Pupil Labs: https://pupil-labs.com/
[4]An example of an interaction with the SR: https://youtu.be/rPM8Re4SWSY

co-presence and attentional allocation (the two first items of the Networked Minds Measure of Social Presence questionnaire [HB04]). We will explore if there are statistically significant differences in any of these measures based on: (a) age, (b) agent, and (c) any interaction between age and agent. Figure 2 shows an example of participant looking at the agent (used to calculate *proportion of time looking at the agent*) and an event of joint attention (used to calculate *time for joint attention*).

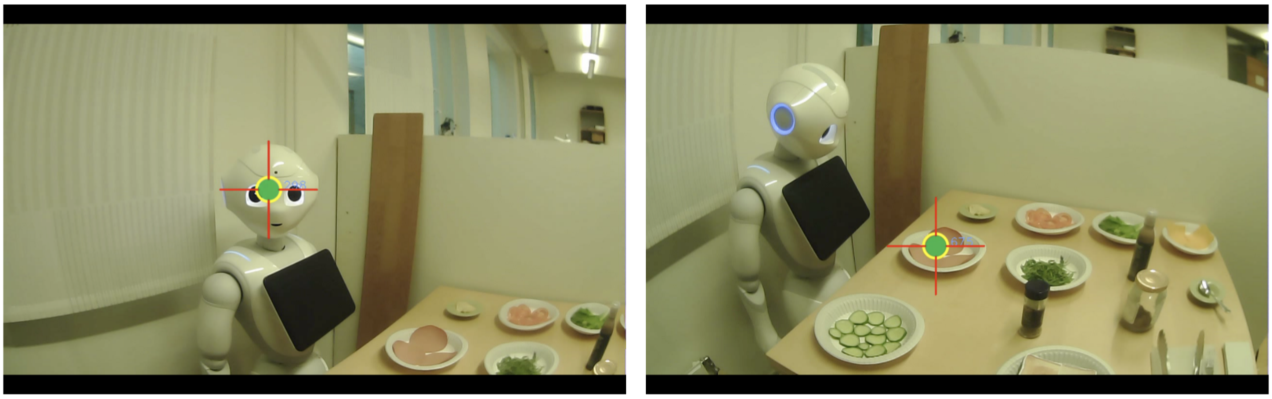

Figure 2: Two frames from the rendered eye-tracker videos. The point at the intersection of the cross shows a fixation, which indicates where the participant is looking at that moment. The left picture shows an example of the participant looking at the agent just before the robot starts an utterance. The right shows a joint attention event, with both agent and participant looking at one specific ingredient while the agent instructs the participant to take it as a next step for the recipe.

5 Conclusion

The aim of this experiment is to explore how the presence of eye gaze cues initiated by an instructor affects the social presence and the efficiency in a collaborative cooking task between two different age groups. We have argued that preference towards social stimuli remains intact in normal ageing, so we do not expect to see differences in preferences for the robots between age groups. However, the question of how an interaction with a social robot that displays eye-cues might shape visual allocation and task performance in ageing has not been explored. Because a higher completion time is expected in the OA group for mobility reasons, we also use the *time for joint attention* in order to understand if there are differences in reaction times in response to gaze initiating joint attention. Regarding differential aspects between robots, we will explore if the trade-off between sociability and task performance that the use of non-verbal cues can cause [KPA+19] is maintained in OA for this specific task. We want to study the extent to which these findings are generalisable to the later stages of life.

This proposal represents a first step towards a multidisciplinary approach between studies in robotics, gerontology and cognitive psychology. The limitations of this study are based on the specificity of the chosen task and the rigid roles that both instructor agent and participants play. The task of preparing a meal only represents one collaborative task among all the possible. However, we have chosen it as a continuation of the work of [KPA+19], as they have reported a trade-off between perceived sociability and task efficiency that we find interesting to investigate under the light of ageing. It is also possible that the attribution of roles to the agent (instructor) and the participant (performer) also influences certain aspects of participant's gaze behaviour, as it has been shown to happen in human-human interaction [MT18]. Future research should use different tasks and roles in order to investigate if the trade-off between perceived sociability and task efficiency remains.

The future outcomes of this study might impact the way social robots for OA are designed. In spite of the importance of developing robotic systems adapted to the specific needs of OA, we consider that it is also important to understand the role of natural interactions in the context of HRI and how these may evolve during the lifespan. By doing this, models for personal robots that adapt to users as they age in terms of efficient interactions could be designed.

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