Anticipation and Proactivity. Unraveling Both Concepts in Human-Robot Interaction through a Handover Example

J. E. Domínguez-Vidal and Alberto Sanfeliu

***Abstract*— While robots have advanced in understanding their environments, collaborative tasks demand a deeper comprehension of human intentions to mitigate uncertainty. Anticipatory and proactive behaviours are pivotal in enhancing Human-Robot Interactions (HRI), yet literature often conflates these terms. This study elucidates the distinction between anticipation and proactivity, offering clear definitions and exemplifying their implications through a handover scenario. Through a user study with 24 volunteers performing a total of 72 experiments, we have found that humans are able to distinguish both behaviours and that there is a statistically significant increase in the anthropomorphism of the robot when it behaves proactively. Additionally, both anticipation and proactivity show statistically significant increases in multiple aspects of effective HRI (fluency, comfort, performance, etc.). However, no clear preference for either has been detected.**

***Index Terms*— Physical Human-Robot Interaction, Handover, Intent Detection, Human-in-the-Loop, User Study**

I. Introduction

In its origins, robotics began by generating machines that could perform small repetitive tasks relieving humans of this burden. Gradually, perception systems improved and with them robots were enabled to perform tasks that required more complex decision making including navigating in urban environments [1] or choosing the right tool to execute their task [2]. However, when the robot must perform a task collaboratively with a human, understanding the environment in which the task takes place is no longer sufficient: the robot needs to understand the human's intention because its behaviour may be too uncertain [3].

The correct understanding of this intention is what, according to some authors [4]–[8], allows the robot to exhibit anticipatory or proactive behaviours. That is, to anticipate the human and even take the initiative and propose actions to them instead of just reacting to their actions. However, if one analyzes the literature [9]–[12], one can observe how the concepts of anticipation and proactivity are used interchangeably as if they meant the same thing.

In this article, instead, we try to distinguish these two concepts by offering a clear and concise definition that can encompass multiple works in the literature being this our first contribution. Subsequently, we show a practical example using the specific use case of handover in which the difference between both aptitudes can be observed, being this our second contribution. Finally, we perform a round of experiments (see Fig. 1) with its respective user study to prove both that the human does perceive the difference and to show the effects that these different skills can have on different aspects of an effective human-robot collaboration, being this our third contribution.

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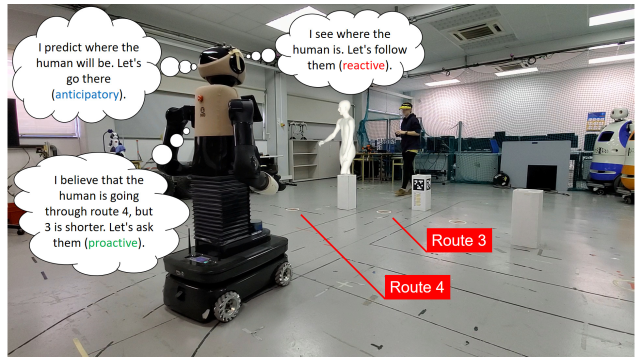

Fig. 1. **Human-robot handover example.** Human and robot must approach to deliver an object hold by the human. Scenario with several obstacles so the human has at least four routes to approach the robot. Robot runs a movement predictor to estimate the human's intention. With it, it can anticipate the human and move to the place they are going to be (anticipatory behaviour) instead of to the place they are currently (reactive behaviour) or even to propose a new route if the human is behaving clearly sub-optimally (proactive behaviour). The human has a microphone to communicate with the robot if necessary and it runs a voice commands recognition system.

In the remainder of the document, in Section II we present multiple works that explore both concepts. Section III presents our definitions and Section IV includes an explanation of the task used in this work as well as all the technical details of the systems used. Section V presents the hypotheses to be tested, the setup and methodology employed as well as the distribution of participants who performed the experiments. Finally, Section VI presents the results obtained and Section VII contains the conclusions.

II. Related Work

Multiple articles using the concept of anticipation in robotics can be found in the literature. Older works [13]–[15] treat this concept in different ways. Thus, [13], [14] defines an agent as anticipatory if it acts on a combination of the existing state and a probabilistic view of the future activity of its teammate and finds that anticipatory behaviour improves perceived fluency and the robot's contribution to performance when compared to reactive behaviour. For its part, [15] takes a completely different perspective and defines anticipatory movements as those that allow the observer to better predict the future action of the performing agent. Other works [16], [17] use anticipation as a synonym for prediction of sequences of future actions or activities that a human will do next. It is also possible to find works [18], [19] that focus on taking advantage of this prediction to improve the robot's behaviour, for example, taking advantage of the gaps predicted to be left by passers-by to allow the robot to move in densely populated environments, although without ever defining what they mean by anticipation. Lastly, [10] also follows this idea of improving the robot's performance by using a prediction of what the human will do but intermingling anticipation and proactivity throughout the article.

In terms of proactivity, one can find works [11] that follow the same approach as [18], [19] but using the term proactive instead of anticipatory to others [20], [21] that do present a different approach. Shvo et al. [20] defines proactive robot behaviour as "act only if needed and if the robot perceives discrepancies" between the robot's and the human's knowledge of the environment. Thus, if the environment has changed without the human noticing, the robot predicts that the human will have a problem in executing their plans and acts to avoid it. In turn, [21] distinguishes between low, medium and high proactivity, with its low proactivity approaching the anticipation used in [18] and its high proactivity approaching that of [20]. It is also possible to find works [22], [23] that, based on psychology, understand proactivity as the maintenance of equilibrium, understood as the optimal execution of a task. This implies that for them proactivity is only possible if a task is being executed suboptimally and the robot can therefore only behave proactively or reactively. Finally, [12] also distinguish between two types of proactivity: one in which the robot detects the human's intention and acts to fulfill it, and one in which the robot detects a possible future danger and acts to avoid it. However, throughout the article they also use the term anticipation interchangeably. To the best of our knoledge, our work is the first to define and differentiate the concepts of anticipation and proactivity.

III. Definition of Anticipation and Proactivity

According to psychology and organizational behaviour studies, proactive behaviour is change-oriented [24], [25]. Likewise, in [26] they consider that behaviours can only be reactive or proactive. In this article, however, we go one step further and, taking into account the considerations of several previous works [12], [13], [18], [20], we consider that behaviours can also be anticipatory, i.e., reactive to a future prediction rather than to the present situation.

Taking into account the above, and based on the assumption that *A* is performing a collaborative task with *B* and that their goal is to complete it successfully, we define:

- The **reactive behaviour** of an agent *A* is that which is produced by acting in consequence of the current actions of an agent *B* perceived by agent *A*.

In terms of proactivity and anticipation, we consider that for any of these behaviours to exist, a prediction of the future

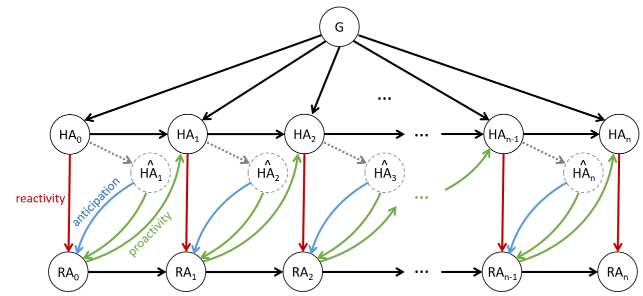

Fig. 2. **Causality relationship between the actions to be performed by each agent for each robot behaviour.** HA_k represents the actions of the human and RA_k the actions of the robot. $k \in [0, n]$ represents each set of jointly considered actions, G the goal of the collaborative task and $\hat{HA}_{k+1}$ represents the prediction of the actions to be performed by the human based on its previous actions HA_k. In black are represented the relationships present in all behaviours. In red those corresponding to a reactive behaviour by the robot, in blue those corresponding to an anticipatory one and in green those corresponding to a proactive one.

state is needed, either of the environment or of the agent with whom one is interacting. Thus, we define:

- The **anticipatory behaviour** of an agent *A* is that which is produced by acting in consequence to the prediction that agent *A* makes about the future actions of an agent *B*, with *A* accepting these actions of *B* and preparing in advance for when they occur.
- The **proactive behaviour** of an agent *A* is that which occurs by acting in consequence of the prediction that agent *A* makes about the future actions of agent *B*, with *A* not accepting these actions but acting in such a way as to avoid that prediction by prompting *B* to perform other actions that are more appropriate, optimal, or safer.

Thus, those works in the literature that make use of controllers [27], [28] to make the robot adapt to the human as quickly as possible would be examples of reactive behaviour, while those solutions based on the use of predictors [8], [10], [13], [18] to make the robot anticipate the human would fit our definition of anticipatory behaviour. Finally, those cases in which the robot analyzes that prediction to make proposals to the human in case it detects some future problem or if the human is behaving suboptimally would correspond to proactive behaviours [12], [20], [21].

Fig. 2 shows an illustrative diagram of the relationship that would exist between the actions of the human HA_k and those of the robot RA_k in each behaviour with the robot being agent *A* and the human agent *B* in the above definitions. Thus, reactivity occurs when the robot's actions only depend on the human's current actions while both anticipation and proactivity take into account a prediction of the human's future actions, $\hat{HA}_{k+1}$, to either be prepared for when this future occurs or to act so that this future does not take place.

Note that this is simplified causal diagram (not a temporal one) intended to be illustrative of the three defined behaviours. In reality, present (and past) actions must also be taken into account to behave anticipatorily or proactively either to generate the necessary prediction or to verify that the robot's actions are having the desired effect.

IV. Anticipation and Proactivity Applied to Handover

Human-Robot handover is a task in which a human and a robot deliver an object by passing it from the hand of one of the agents, the giver, to that of the other, the receiver. This task can be performed in close proximity, so that the robot only has to move its arm, or at some distance, implying that it must also move its platform. Depending on the distance, three or four phases can be distinguished: approaching, pre-contact, contact and release [7]. The first phase corresponds to the long distance appoach, the second to the negotiation between the two agents about where the object is finally delivered and in what posture, the third to the grasping by the receiver and the fourth to the giver releasing the object once they are sure that the receiver has a firm grip on it. It is, therefore, a task that is performed quickly and in which human and robot end up being in close proximity. This implies that short response times are required but without making the robot's movements abrupt so as not to endanger the human.

In this work, we will focus on the first two phases, not delivering the object, thus ensuring that there is always a safe distance between the human and the robot. Robot and human will start from a distance of about 5 m and the human will always act as the giver. The scenario used presents several obstacles so that the human has several routes to approach the robot (see Fig. 1) allowing the occurrence of the three behaviours defined in the previous section.

To detect the human's actions, in this case, their movements, the robot uses an RGBD camera in its head focusing on the human. With this and using the Mediapipe[1] library, the robot can detect the human and, more importantly, the position of the hand in which they are holding the object to be delivered. Thus, in order for the robot to exhibit a reactive behaviour, we make it periodically plan its movements (platform and arm) to approximate the current position of the human's hand. In this way, at each planning cycle, the robot will recalculate its movements consistently with those of the human.

A. Prediction of Future Human's Movements

In order to act in an anticipatory or proactive way, however, the robot needs a prediction of the actions to be performed by the human. In this case, its movements. For this purpose, we will use the trajectory predictor developed in [29], which using a Deep Learning model based on Graph Convolutional Networks (GCN) allows to predict the trajectory that the human will describe during the next 2.5 s applied to a handover task.

Thus, to make the robot behave in an anticipatory manner, we will use the same replanning system as with the reactive behaviour but making the robot to plan with respect to the position that the predictor estimates the human's hand will occupy 2.5 s instead of to its current position. This ensures that planning time is approximately the same not affecting posterior human valuation. Thus, the robot can be prepared in advance to human's movements.

[1] https://developers.google.com/mediapipe

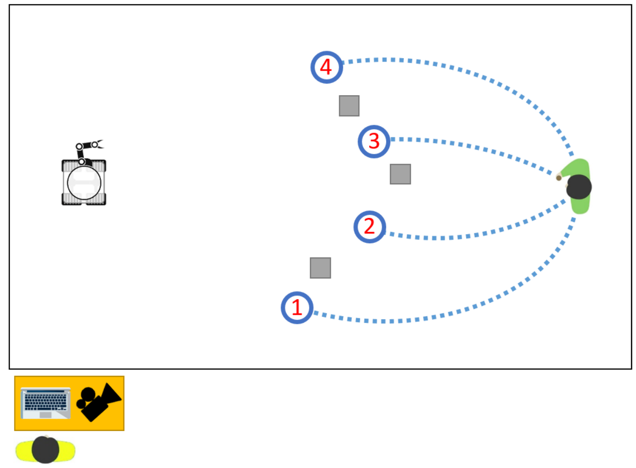

Fig. 3. **Experiments setup.** Scheme of the designed setup. Due to the present obstacles, the human has at least four routes to approach the robot. Control desk on the bottom with researcher managing the experiment and camera recording for posterior analysis.

B. Proactivity through Direct Communication

In order to exhibit a proactive behaviour, in addition of using the above predictor, the robot will analyze this prediction to detect when the human is clearly behaving suboptimally. In this case, it will detect when the human has chosen to approach along an excessively long route (see Fig. 3).

Since in principle the reason for this choice of the human cannot be known (it could be intentional, due to ignorance or because the human possesses additional information to that of the robot), we decided that the robot's proactive behaviour would consist of communicating directly with the human, indicating that there is a shorter route than the one they are using and asking them which route they prefer. Using a microphone and a voice command recognition system [30], the human can tell the robot whether they maintain their choice or whether they prefer the alternative proposed by the robot.

V. Evaluation

We conducted a round of experiments with a within subjects study to test what effect each behaviour mode has on multiple aspects of an effective Human-Robot Interaction (HRI) as well as what preference the human may have.

A. Experiments Setup and Methodology

Both the robot's and the human's starting point are preset and are the same in all the experiments. Both positions are at a distance of 5.0 m, since this was the maximum distance at which Mediapipe could detect the human. The robot used is IVO [31], which has an RGBD camera in its forehead and can perceive obstacles by means of its front LiDAR. The robot's linear velocity is limited to 0.4 m/s and the approach has a minimum distance of 0.1 m to ensure human's safety.

Each volunteer performs four executions with each behaviour (reactive, anticipatory and proactive), to ensure that they can observe how the robot acts for each possibility (shorter routes or longer routes). To ensure that variations in the order of the routes do not subsequently affect the volunteer's assessment of each behaviour, this order is chosen randomly at the beginning of the experiment (e.g., 1234, 3412, ...) for each volunteer and is repeated for each behaviour. In turn, the order of the three behaviours faced by each volunteer is randomly assigned to avoid statistical distortions[2].

At the end of the four executions of each behaviour, each volunteer fills out a handmade questionnaire to assess both numerically from 1 to 7 and by choosing among the different behaviours tested different aspects associated to an effective HRI. The numerical valuations are then analyzed using different tests. First, the Saphiro-Wilk's and Levene's tests are applied. If the variable analyzed meets the normality condition, an ANOVA test with Bonferroni correction is applied to check whether there is a statistically significant variation (p<0.05), in which case, a Tukey's HSD (Honest Significant Difference) test is applied. If the normality condition is not met, a non-parametric Kruskal-Wallis test is applied followed by a Nemenyi's test if statistically significant variation is detected between the three behaviours. A control question is also added to check that volunteers differentiate between the robot reacting to their movements and the robot anticipating them (anticipation and proactivity). After filling in the questionnaires, a short interview with three open questions is conducted: What did you think of the whole experiment? What were your feelings during each attempt? What would you improve?

B. Hypotheses

In line with what can be found in the literature [10], [13], we consider the following hypotheses:

H1 - The human is able to differentiate between the robot simply reacting to their movements and it trying to anticipate them.

H2 - The human tends to attribute more anthropomorphic qualities to the robot if it behaves in an anticipatory/proactive way than if it behaves in a reactive one.

Additionally, we consider the following hypotheses:

H3 - Exhibiting an anticipatory/proactive behaviour improves multiple aspects of an effective HRI compared to reactive behaviour.

H4 -The human prefers the robot to behave proactively over any other behaviour.

C. Participants

A total of 24 volunteers, aged between 21 and 56 ($\mu = 29.58$, $\sigma = 7.31$), performing 72 experiments (3 each) were recruited from our research institute as well as from different schools of the partner university. Their self-valuated subjective knowledge of robotics from 1 (none) to 7 (expert) was 4.00 ($\sigma = 1.35$).

[2]Experiments example: `https://youtu.be/ZApxxnm7uJU`

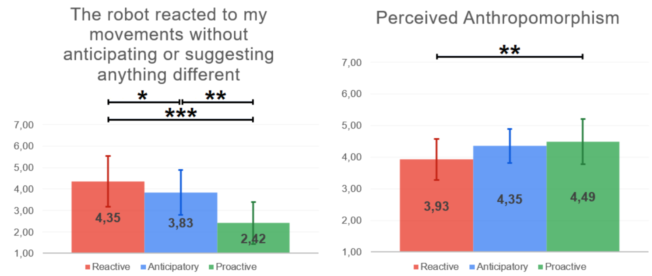

Fig. 4. **Assessment of the perceived robot's reactivity and anthropomorphism.** *Left:* Comparison among the subjective valuation of the control question used to check if the human is detecting when the robot is behaving just reactively. *Right:* Comparison of subjective valuations of the Godspeed questionnaire's anthropomorphism block of questions. Reactive behaviour in red, anticipatory behaviour in blue and proactive behaviour in green. Valuation from 1 (very low) to 7 (very high). Statistical significance marked with *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$. Bars represent std. dev.

All the experiments reported in this article have been performed with the approval of the ethics committee of the Universitat Politècnica de Catalunya (UPC) in accordance with all the relevant guidelines and regulations and all the volunteers have signed an informed consent form. No volunteer was paid for participating in this study, ensuring that there is no conflict of interest.

VI. Results

Before analyzing this round of experiments, we perform a post-hoc statistical power test to know what values we can be statistically sure of. Thus, using the criterion of $p < 0.05$, with 24 volunteers, we can detect effect sizes as low as η^2=0.127 with a statistical power of 80%. All variables analyzed by variance tests are normally distributed according to the Shapiro-Wilk's test unless otherwise indicated.

To test hypothesis **H1**, we added a control question in our questionnaire to ask the volunteer to rate whether they agree (7) or disagree (1) that the robot is only reacting to their movements. Fig. 4 - *Left* shows the result for all three behaviours. Because this variable fails the Shapiro-Wilk's test, a non-parametric Kruskal-Wallis test is applied detecting that a statistically significant variation occurs: H=33.36, p<0.001. Next, a Nemenyi test is run to check between which pairs of behaviours there are statistically significant differences. Both anticipatory (p=0.048) and proactive behaviour (p<0.001) produce statistically significant variations when compared to reactive behaviour. Finally, there is also a statistically significant reduction when comparing proactive with anticipatory behaviour (p=0.0021). **H1** is therefore **confirmed**.

To test the hypothesis **H2**, we used the questions corresponding to the "Anthropomorphism" block of the well-known Godspeed questionnaire. Fig. 4 - *Right* shows the result. This variable does pass Shapiro-Wilk's and Levene's test so that an ANOVA test can be run detecting that there is a statistically significant increase: $F(2, 69)$=5.14, p=0.0083, η^2=0.130; proactive VS. reactive: p=0.0082. While proactive behaviour does manage to significantly increase the volunteers' rating of the robot's anthropomorphism, the same is

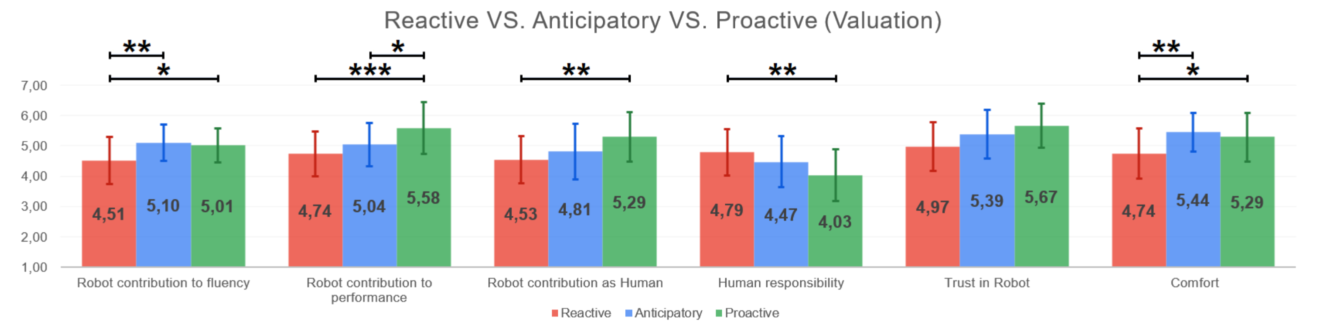

Fig. 5. **Assessment of the main aspects involved in the interaction.** Comparison among the reactive behaviour in red, anticipatory behaviour in blue and proactive behaviour in green. Valuation from 1 (very low) to 7 (very high). Statistical significance marked with *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$. Bars represent std. dev.

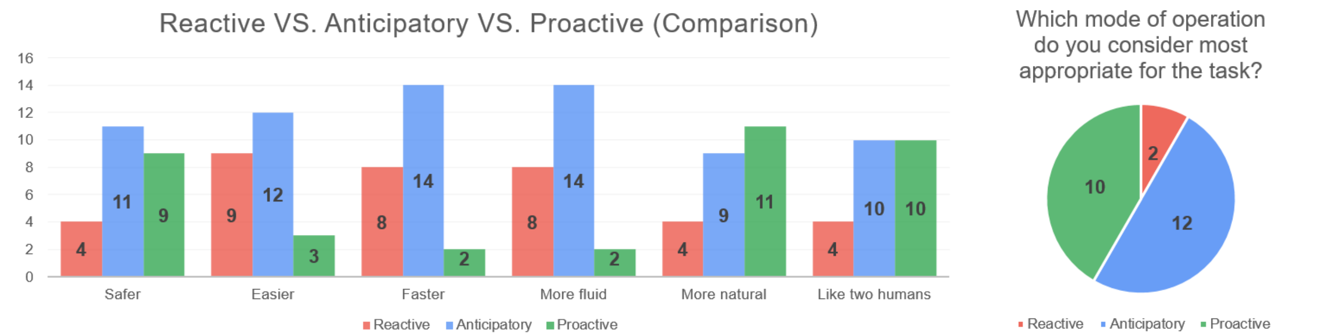

Fig. 6. **Direct comparison among using each one of the three behaviours.** *Left* - Election made by the volunteers instead of valuate aspects numerically *Right* - Election made by the volunteers with respect to which system they consider performs better at the task at hand. The maximum is 24 in both cases as it is the number of volunteers.

not true for anticipatory behaviour (p=0.061). **H2** is therefore **partially rejected**.

To test **H3**, the volunteers are asked to rate from 1 to 7 multiple aspects corresponding to an effective HRI. Fig. 5 shows the result. As it can be seen, statistically significant variations occur for all variables except in "Trust in Robot" where we have not sufficient statistical power ($F(2,69)$=4.85, p=0.0011 η^2=0.123). These variations are larger for anticipatory behaviour with respect to proactive if we compare both with the reactive one in "Robot contribution to fluency" ($F(2,69)$=5.50, p=0.0061, η^2=0.137; anticipatory VS. reactive: p=0.0086) and in "Comfort" ($F(2,69)$=5.72, p=0.0050, η^2=0.142; anticipatory VS. reactive: p=0.0056). On the other hand, proactive behaviour achieves greater variations with respect to anticipatory behaviour when both are compared to reactive behaviour in "Robot contribution to performance" ($F(2,69)$=7.31, p=0.0013, η^2=0.174; proactive VS. reactive: p<0.001), "Robot contribution as Human" ($F(2,69)$=5.18, p=0.0080, η^2=0.131; proactive VS. reactive: p=0.0062) and in "Human responsibility" ($F(2,69)$=5.25, p=0.0075, η^2=0.132; proactive VS. reactive: p=0.0054). Since both modes of behaviour manage to improve multiple aspects of an effective HRI, we can say that **H3** is **confirmed**.

To test hypothesis **H4**, volunteers are asked, after having performed all experiments, to explicitly choose among the three modes of behaviour with respect to multiple parameters. Fig. 6 - *Left* shows the result. As it can be seen, behaviours that make use of a prediction of the human's actions are perceived as safer, with no preference between anticipatory and proactive. As for the ease with which the task can be executed, the preference is clear for systems that do not use explicit communication with the human but adapt to them. As to which system makes the task run faster or more smoothly, there is a strong preference for anticipatory behaviour followed to a lesser extent by reactive behaviour, since neither of which generates any interruption. However, as to which behaviour is more natural or more similar to how two humans would act, there is a technical draw between anticipatory and proactive. Finally, if volunteers are asked to choose the behaviour they consider overall more appropriate for the task, a draw also emerges between anticipatory and proactive behaviours (see Fig. 6 - *Right*). Since there is not a clear preference towards proactive behaviour over the other two, **H4** is **rejected**.

Some of the volunteers' comments in the post-experiments interview confirm these results. Volunteer 5 said "*The first one* (anticipatory) *reacted faster, as if it knew where I wanted to go*". Volunteer 14 commented "*Asking me* (proactive) *makes the robot look smarter, and it takes responsibility away from me when doing the task*". Volunteer 21 said "*I'm not sure about which one I prefer. The last one* (anticipatory) *was very quick to adapt to what I wanted to do, which is the funny part of working with a robot, but the previous one* (proactive) *would communicate with me if I do something stupid, which is what I would do with someone else*".

VII. Conclusions

In this work, we have show that in the literature the terms anticipation and proactivity tend to be used interchangeably. In an attempt to solve this issue, we have provided our definitions so that each concept can be clearly differentiated and, at the same time, encompass multiple works present in the literature.

Through a round of experiments, we have used a handover task as a test-bed to show a case study in which these behaviours can be observed. Through the ensuing user study, we found that humans can indeed differentiate these behaviours and that they perceive the robot as more anthropomorphic when it acts proactively. We also found that both anticipation and proactivity enhance multiple aspects of an effective HRI. However, because each behaviour has its main effect in different aspects, we did not detect a clear preference of the human toward either behaviour.

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