User perception of robot's role in floor projection-based Mixed-Reality robotic games

User Perception of Robot's Role in Floor Projection-based Mixed-Reality Robotic Games

F. Gabriele Pratticò, Alberto Cannavò, Junchao Chen and Fabrizio Lamberti
Dipartimento di Automatica e Informatica, Politecnico di Torino, Torino, Italy
filippogabriele.prattico@polito.it, alberto.cannavo@polito.it, junchao.chen@studenti.polito.it, fabrizio.lamberti@polito.it

***Abstract*—Within the emerging research area represented by robotic gaming and, specifically, in application domains in which the recent literature suggests to combine commercial off-the-shelf (COTS) robots and projected mixed reality (MR) technology in order to develop engaging games, one of the crucial issues to consider in the design process is how to make the player perceive the robot as having a key role, i.e., to valorize its presence from the user experience point of view. By moving from this consideration, this paper reports efforts that are being carried out with the aim to investigate the impact of diverse game design choices in the above perspective, while at the same time extracting preliminary insights that can be exploited to orient further research in the field of MR-based robotic gaming and related scenarios.**

***Index Terms*—Human-robot interaction, game design, user experience, projection-based mixed reality, phygital play, robotics.**

I. Introduction

The interest in robots has continuously grown in the last years, with applications ranging from research prototypes to concrete tools supporting our daily activities, e.g., in the form of commercial off-the-shelf (COTS) products. Service robots (vacuum cleaners, lawn mowers, etc.) and toy robots, in particular, are getting more and more common. While technology is evolving, industry and academy are devoting significant efforts in improving human-robot interaction (HRI) [1], with the aim to raise acceptance and foster adoption at the consumer level.

One of the emerging trends that pertains social robotics and HRI is their application to gaming. Although the rise of Artificial Intelligence (AI) is providing us with ever more sophisticated techniques that can be exploited to make robots ever smarter and characterized by more reliable and believable behaviors, so far the most common approach to drive them in the context of gaming is teleoperation. Unfortunately, the limited scope and flexibility of existing solutions combined with unnatural HRI paradigms generally lead players to boredom.

With the aim to promote player-robot interaction in the context of a more engaging game experience, a major trend that has recently gained momentum consists in immersing existing robots and players in a mixed reality (MR) environment created by "augmenting" the physical world with digital contents. In [2], several approaches developed in this direction are presented, classified based on the environment selected as the playground (indoor/outdoor) and on the technology used for delivering the digital augmented contents to the user.

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One of the configurations that has been explored leverages an indoor projection-based MR playground. Several games were developed under this category [3]–[13], encouraged by the fact that, through this approach, consumer-ready robots originally meant for a specific application can be given a "new life", thus promoting reusability. It is worth observing that games conceived for this technology do not necessarily have to be focused on pure entertainment: there are examples tailored, among others, to education, training and rehabilitation purposes.

An additional aspect to consider when classifying these solutions is represented by the particular HRI paradigms adopted. In this respect, an emerging category is that of so-called Physically Interactive Robotic Games (PIRGs) [14], which promotes the role of robots as rational agents that may interact with players in a physical (and safe) way. PIRGs are part of a more general approach to the problem of HRI in games that was introduced in [12] and referred to as *phygital play*: according to this concept, robots and other concrete elements are expected to make playing with digital content more engaging thanks to the higher level of immersiveness ensured by the "physicalization" of the experience.

One of the challenges that game designers face when creating these kinds of experiences concerns how to effectively take advantage of the physical presence of the robot in the game scenario, without making it be perceived as "just another" gaming element. Even though in [14] a general set of guidelines were presented to tackle this issue, it is not completely clear yet what could be the effect of different design choices on the possible role played by the robot in the game, its appearance, behavior, etc. from the point of view of user experience.

Moving from this consideration, in this paper we aim to share the preliminary outcomes of a study that we are carrying out to investigate the above perspective within the broad design space of projected MR-based robotic games.

II. Related Work

In the recent literature, it is possible to find several proposals related to robotic games leveraging projection-based MR. For instance, in [4], a possible approach to HRI is investigated by exploiting the physical components of the robot as a tangible interface that lets the player interact with the robotic companion in a shared playground. A comparable interaction space with player and robot sharing the same gaming area is exploited in [5], but in this case virtual projected contents are used to demonstrate that, by pushing on context-based expressions, perceived life being connotation of the robot could be made more effective. A shared playground is used in [6] as well, though no physical contact is envisaged.

Player and robot can also be put far away like, e.g., in [7]. In this case, only the robot is allowed to move on the projected playground; the player is located outside that area, and can interact with the robot via a gamepad controller. This kind of interaction is adopted also in [8], where it is declined in a multiplayer–multirobot perspective.

Robot and player can even be confined to the edges of the projected playground or limited in their movements. For instance, in some applications the robot has been forced to follow predefined paths [9] or even to move just along a line [10], exploiting the virtual projection area not (only) provide the context for the game but (also) to express the principal game mechanics and resources.

In most of these games, competitive dynamics are implemented, although different goals have also been considered. An example is provided in [11], where collaborative gaming mechanisms between the player and the robot have been experimented.

Games above comply with one or more of the design guidelines proposed in [14], though often not all of them. For instance, one of the most relevant recommendations is to make the robot appear as a rational agent, meaning that expedients need to be used to ensure that players consider it as a "peer", thus privileging autonomous behaviors to direct control (e.g., with the robot teleoperated by another player). As seen, not all the implementations actually rely on autonomous robots.

Most importantly, the design of most, if not all, of these works followed a technology-driven approach, which is indeed a very good way to prove that the technology developed is effective to support the experience; however, this approach may sometimes prevents the definition of a consistent user experience, whose realization could be better addressed by resorting to design-driven methodologies. In that way, technology could be better put at the service of the user, rather than vice versa.

The richness of the above review suggests that it is quite difficult to compare so many different games to identify and extract common cues that can be exploited to design effective projected MR-based robotic games. As said, also with the aim to adhere to phygital play principles, we are especially interested in design principles to be considered in order to create games capable to put the robot "at the center of the interaction", e.g., by establishing it as not easily replaceable by its projected surrogate without affecting the overall game experience.

It also true that introducing variations in the existing games

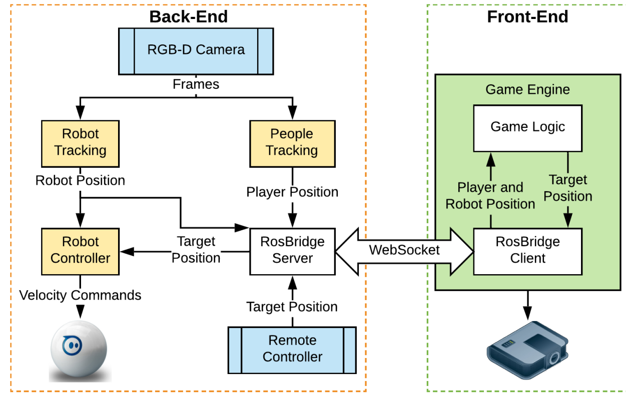

Fig. 1. Architecture of the cloud- and SAR-based robotic gaming platform.

to study their impact on perceived user experience would be an unpracticable path, both because most of them rely on a specific technology layer, as well as because it may be virtually impossible to alter the defined game mechanics without destroying the fun part of the game.

III. Game Design and Implementation

To deal with the above issue, in this paper a new game is proposed, which is designed *ad hoc* and endowed with simple mechanics in order to make it easy to introduce variants to game design elements and ultimately allow researchers and designers to isolate the contribution of each of them on the perceived importance of the robot in the overall game experience.

A. Technologies

The developed game leverages the technological capabilities of the Spatial Augmented Reality (SAR) cloud-based robotic platform already presented in detail in [10] and [15]. The high-level architecture of this platform is conveniently reported in Fig. 1.

Moving from the original configuration, a different robot was integrated. As discussed in the Section II, one of the game design choices that is worth to be investigated relates to the robot's movement capabilities w.r.t. to the gaming area. For this reason, differently than in [10], a holonomic COTS robotic platform, namely, the *Sphero 2.0* toy robot, was selected.

Sphero is a spherical robot composed of a white orb wrapped in polycarbonate plastic which protects its internal components in an entirely self-contained and sealed device. It is equipped with a 3DOF accelerometer and gyroscope, whose data can be retrieved via the native SDK[1]. In addition, an unofficial SDK for the well-known Robot Operating System (ROS) is available, which made the integration with the existing platform effortless.

The communication with the robot is established by leveraging its built-in Bluetooth connectivity. The position of the robot is controlled using computer vision- and PID-based

[1]https://sdk.sphero.com/

tracking algorithms [15], which are fed with the desired target position. It is also possible to utilize a predefined set of animations for the robot created by mixing color changes and pre-recorded movements with the aim to encode emotional traits (like happiness or sadness). The platform is also endowed with player tracking capabilities, which allows it to determine player's position in the gaming area, as well as performed gestures. This feature relies on the Microsoft Kinect v2 SDK[2].

Each physical element of the game (i.e., robot and player) has a virtual counterpart, which mimics the movement of the physical entity in the game logic by using tracking data from the robot and the player. Virtual representations are exploited by the game logic to correctly simulate interactions between all the game elements, thus creating the illusion that the physical world can affect the digital one, and vice versa. Moreover, the robot features an additional virtual counterpart, which represents its target position that has to be provided to the robot controller module. The player's counterpart consists of a circular area, whose diameter is calibrated to match the player's shoulder width; this area is also projected on the floor during the game as a red circle to provide continuous visual feedback to the player.

B. Game Design and Implemented Variants

As said, the aim of this work is to evaluate the impact that a given design choice can have on the perceived centrality of the robot in the game experience.

To this aim, a game named *Protect the treasure* was designed. In particular, a basic version of the game was initially ideated, lowering down the complexity of game mechanics [16] as much as possible; then, this reference design was declined in other nine different game variants, or modes, each exploring only one dimension at a time of the possible design space. The game was designed with the PIRG principles in mind, ending up with a game experience in which the player and the robot interact by means of the projection-based MR environment.

The so-called *Basic* mode of *Protect the treasure* consists of a competitive attack-defense game. The whole floor projection is used as the game playground. During the game, the area is populated by collectibles virtual objects (treasures). The robot, in the role of the attacker, has the objective to catch them. The player, acting as the defender, has the goal to prevent that from happening. The attacker wins the game if it succeeds in collecting a certain number of treasures in a given time; otherwise, defender is the winner. In order to prevent the robot from collecting a treasure, the player must interpose its body (precisely, its virtual counterpart represented by the red circle) between the treasure and the attacker.

The other game modes were generated by exploring possible variations of the elements below.

- *Physical Robot*: it can be physically present in the gaming area or just virtually projected on the floor.
- *Player role*: the player can be an "active" defender, or use another "proxy" element as a defender.
- *Player control*: the player can move its virtual counterpart either by wandering in gaming area (that is, control is based on the position of its body), with a gamepad or by finger pointing to a desired location on the playground.
- *Player position*: the player can move its virtual counterpart from inside the playground (with its body) or outside of it.
- *Robot role*: the robot can be an attacker, or eventually a defender; in the latter case, the role of the attacker will be taken by another virtual element.
- *Robot control*: control can be actuated by the AI in the game logic. Alternatively, target position can be provided locally using either a gamepad controller or with finger point interaction, or remotely via teleoperation. Teleoperation is intended to be managed by a player that is not co-located with the robot, but rather interacts with it by exploiting the networking capabilities of the cloud-based robotic platform [12]. Teleoperation is actuated via a remote terminal (computer) and its keyboard or any other controller attached to it. In this case, a camera is needed to frame the local playground and deliver a real-time video representation of it to the remote player.
- *Game mechanics*: game mechanics and challenges provided by the game can be altered (e.g., intensified), thus defining diverse user experiences.

By working along the above dimensions, 10 game modes were implemented overall, as reported in the following (when a behavior is not specified, it can be assumed to be the same as in the Basic mode).

- *Basic* (Fig. 2a): as said, both the robot and the player are physically present in (are inside) the playground. The player controls its counterpart using its body (body position). The robot, acting as an attacker, is controlled by the AI in the game logic.
- *Projected* (Fig. 2b): the physical robot is suppressed in favor of its projected counterpart. In this mode, the virtual attacker assumes the same behavior as in the Basic mode.
- *Extended* (Fig. 2c): game mechanics are intensified. A new set of collectible virtual objects and resources are made available to both attacker and defender. The structure of the game spans five levels, with each level introducing one of the following elements incrementally: (i) missiles, which can be thrown by the defender (player) using a body gesture (raising quickly the right arm), have the effect to stun the attacker for few seconds; (ii) ice traps, which can be positioned by the defender and are invisible to the attacker until it hits them causing a temporary stun, and disappear automatically if not activated within a defined amount of time; (iii) bombs, which can be used by the attacker and let it get an extra point when the defender is hit (like when a treasure is collected).
- *Player Direct* (Fig. 2d): the player and the robot are

[2]https://go.microsoft.com/fwlink/p/?LinkId=403899

TABLE I
DIFFERENCES AMONG THE DEFINED GAME MODES

Game mode	**Player role**	**Player position**	**Player control**	**Robot role**	**Robot control**
Basic	Defender	Inside	Body position	Attacker	Game logic AI
Basic Projected	Defender	Inside	Body position	Attacker	Game logic AI
Extended	Defender	Inside	Body position + Body gestures	Attacker	Game logic AI
Player Direct	Defender	Outside	Gamepad	Attacker	Game logic AI
Coop. Remote Robot Direct	Proxy	Outside (through display)	Proxy	Defender	Gamepad
Coop. Robot Direct	Proxy	Outside (close to playground)	Proxy	Defender	Gamepad
Cooperative	Defender	Inside	Body position + Finger pointing	Defender	Finger pointing
Finger pointing Player Direct	Defender	Outside	Finger pointing	Attacker	Game logic AI
Remote Player	Defender	Remote	Teleoperated	Attacker	Game logic AI
Multiplayer Remote Robot	Defender	Inside	Body position	Attacker	Teleoperated

co-located, but the player controls its virtual counterpart using a gamepad from outside the playground.

- *Cooperative Remote Robot Direct* (Fig. 2e): the robot is controlled by the player using a gamepad and acts as defender (proxy); the attacker role is taken by one or more additional actors (in current implementation, virtual ghost characters). In this mode the player sees the game through a display.
- *Cooperative Robot Direct* (Fig. 2f): as in the cooperative remote robot direct mode the robot is controlled by the player as defender using a gamepad. Robot acts as defender and virtual characters (ghosts) play the role of the attackers. W.r.t to the previous mode in this case the player is placed close to the playground area, directly seeing the game.
- *Cooperative* (Fig. 2g): the robot collaborates with the player (both are defenders), and is controlled via finger point interaction; that is, the player is inside the playground, and controls the position of its counterpart with the body while pointing down with its finger a location on the playground to specify the target position for the robot. As in the previous game mode, additional attackers are introduced.
- *Finger pointing Player Direct* (Fig. 2h): the player controls its virtual counterpart using finger point interaction from outside the playground.
- *Remote Player* (Fig. 2i): player controls its virtual counterpart from remote.
- *Multiplayer Remote Robot* (Fig. 2j): the robot, acting as an attacker, is teleoperated from a remote location by another player.

Besides interaction feedback already discussed, as suggested by [13] for each different mode, the robot, its virtual counterpart, and possible additional actors provide supplementary encoded emotional responses mentioned in Section III.A.

Differences among the various modes are summarized in Table I and depicted in Fig. 2. Several illustrative videos, one per mode, are also available at http://tiny.cc/dtq05y.

IV. EXPERIMENTAL RESULTS

In this section, we present the results of a preliminary user study that is being carried out by using the devised game to

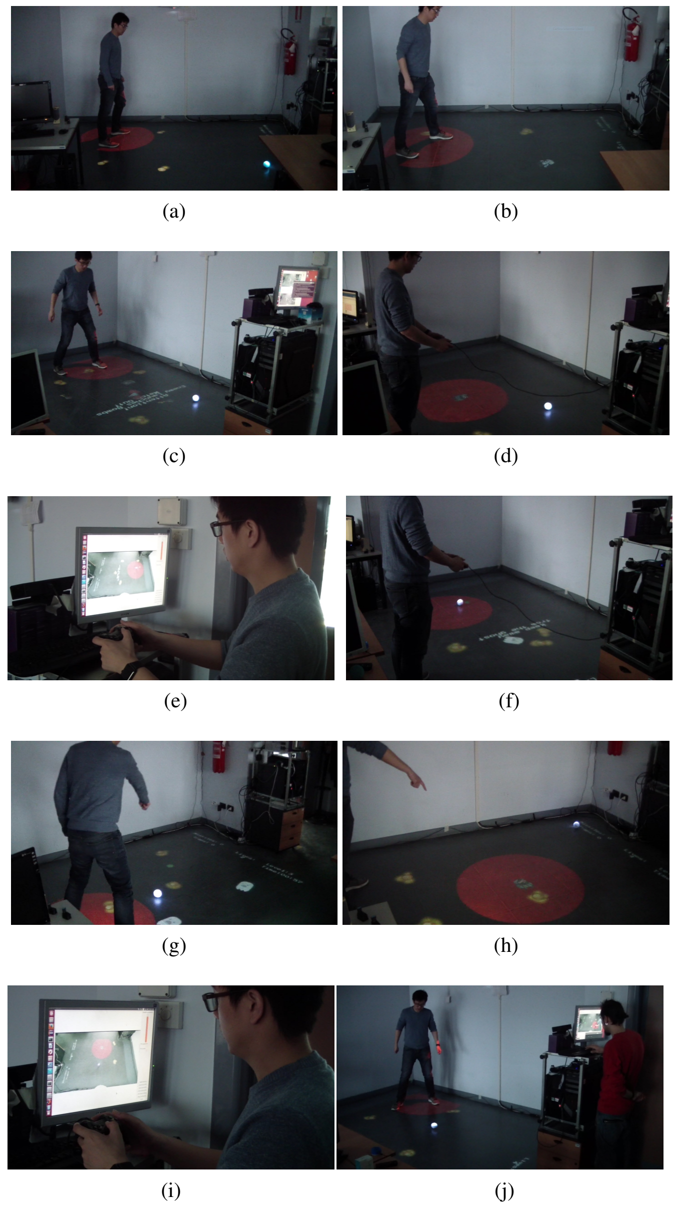

Fig. 2. The 10 game modes implemented in *Protect the treasure*.

evaluate the impact of the considered design choices. In particular, in the batch of tests discussed herewith, the dimension concerning the physicality of the robot is investigated.

The population of the study included 15 volunteers, selected among university students. Each volunteer was requested to play both Basic and the Projected mode; seven volunteers played the Basic mode first, then the Projected mode, whereas remaining volunteers played the game in the reversed order with the aim to reduce possible learning effects.

Before the experience, all the players were asked to respond to a pre-test questionnaire designed to investigate their previous knowledge and expertise with technologies related to those used in the game. After the experience, players were asked to respond to a post-test questionnaire by expressing their agreement with several statements on a 0 to 4 scale (from strongly disagree to strongly agree). The post-test questionnaire consisted of four sections. The first section, named, *System usability*, focused on usability, usefulness, satisfaction, ease of use, and feedback of the technological setup. It was based on Nielsen's Attributes of usability [17] (learnability, efficiency, memorability, errors, and satisfaction), and added specific questions on the perceived quality of visual and audio feedback provided by the system. The second section, named *Game experience*, explored the way players perceived the game experience (e.g., if they felt bored or challenged, what was their sentiment about the interactivity of the game considering the robotic element and the projected playground). The third section, named about *Enemy's animacy and intelligence*, specifically investigated the perceived animacy and intelligence of the opponent. In this section, players were provided with a list of coupled antonym adjectives and they had to say which one was, in their opinion, more appropriate to describe the experienced opponent's behavior on a scale from 0 (the first adjective) to 4 (the second adjective). Lastly, players were asked to express and motivate their preference w.r.t. the two modes, by providing a feedback about positive and negative aspects of both. The questionnaire is available for download at http://tiny.cc/pvq05y.

Collected feedback was analyzed by means of paired Student's t-tests. Results are reported in Fig. 3 and 4. For sake of brevity, only values that are statistically significant ($p < 0.05$) are reported. Flipped values are marked with $*$.

The general outcome of the study is that testers preferred to play the Basic mode, i.e., the mode with the physical robot. Concerning *System usability* (first five questions/statements in Fig. 3), is worth observing that system's feedback was perceived as more clear end effective in the Basic mode than in the Projected mode, although players found it easier to deal with errors while playing the Projected mode. W.r.t. to the *Game experience* (questions/statements from 6 to 1 in Fig. 3), players felt much more challenged by the mode with the physical robot. Overall, players judged the quality and mechanics of both game modes as good. However, based on results concerning *Enemy's animacy and intelligence* (Fig. 4), the presence of the physical robot boosted their perception of playing against a lifelike interactive and alive entity much more than with the Projected mode; in this latter mode, opponent's behavior was considered more simplistic, even though the two modes shared the same AI-based control. As expected, the physical robot was regarded as far more visible than the projected one, which suffers also from player's occlusions. Finally, the general trend is also confirmed by the overall preferences, with 14 out of 15 players preferring the mode with the physical robot.

It is worth noticing that similar results were obtained already in [10], though with a different game and a different robot. Nevertheless, results obtained in this study clarify motivations for users' preference for the physical robot over the projected one; moreover, feedback collected through open-ended questions at the end of the post-test questionnaire suggest that robot's physical presence needs to be further valorized in the game design process, by making the robot move throughout the whole playground rather than confining it to its edges.

V. Conclusions and Future Work

In this paper, we presented a MR-based PIRG leveraging floor projection that, thanks to its highly configurability, can support the study of the design elements which can influence the effectiveness of robotic gaming experiences. In particular, the aim is to help to identify aspects that can have an impact on the way the robot is perceived by the players, so that next game designs can push on those features that contribute at making it play a key role.

Several dimensions of the game design space were isolated and integrated into specific game variants. A preliminary user study conducted over two of these variants confirmed the preference of players for experiences encompassing a physical robot, and suggested that is preferable to have the robot and the player exploiting all the playground space for movement rather than to confine them on the edges of the gaming area.

Future work will be focused on extending the experimental evaluation to a large number of subjects while testing all the game variants with the aim to investigate the whole design space of interest, by possibly introducing additional game modes to better clarify motivation for players' preferences and feedback.

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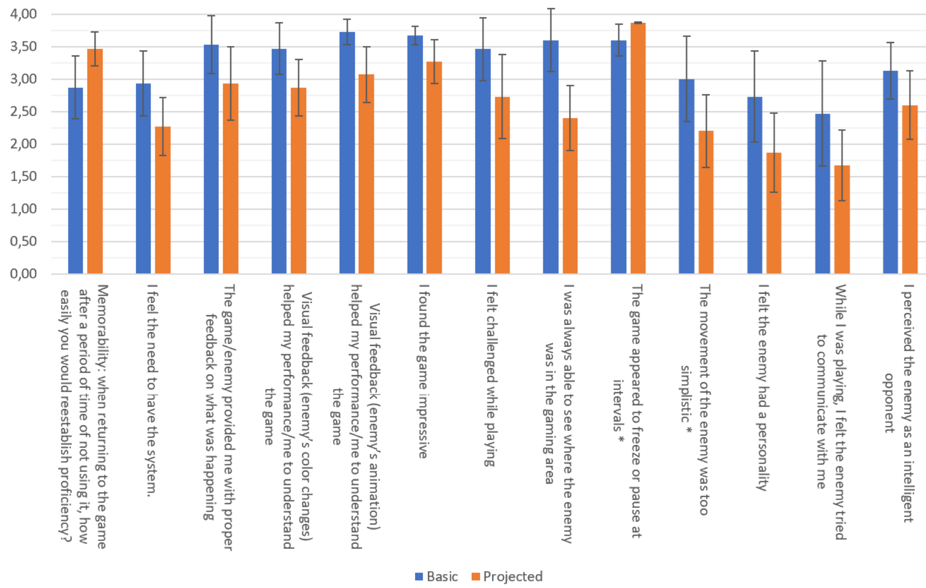

Fig. 3. Statistically significant results from the post-test questionnaire, sections on System usability and Game experience.

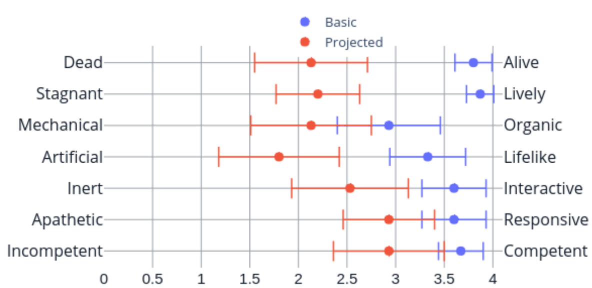

Fig. 4. Statistically significant results from the post-test questionnaire, section on Enemy's animacy and intelligence

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