Supporting Shared Leadership in Human-Robot Teams with Minimal Robot Behavior

Judith Weda

July 3, 2018

Master Thesis HMI
Committee: Prof. dr. V. Evers, Dr. M. Theune, J. H. Vroon, Msc. , C. Zaga, Msc.

Abstract

In this thesis we explore how a minimal robot in a human-robot team can influence shared leadership. The robots currently working in human-robot teams are minimal robots: functional robots that have limited social affordances and communicate only with simple, non-verbal behaviors. Shared leadership allows every team member, including the robot, to join in the decision making process giving them voice. Thus, using the knowledge of different team members including the robot. A robot could support shared leadership in a human-robot team through constructive behaviors, but can be constructive in multiple ways. For example by showing active behaviors, by taking initiative, and passive behaviors, by following orders. In order to answer how robot behaviors in a human-robot team exactly influence shared leadership, we designed and validated (n = 107) active and passive constructive interaction patterns. We also designed and executed an experiment (n = 68) to test the influence of the two interaction patterns on shared leadership. We found a significant difference, namely participants rate each other higher in problem solving in the passive condition, and participants talk more in the active condition. Our findings suggest that an active robot is able to achieve voice and share in leadership, which can reduce the voice of the human team members. This thesis contributes to HRI research by showing how a robot could share in leadership of a human-robot team through voice, and provides design implications for a robot to share in leadership using non-verbal behaviors by showing minimal behavior designs and their effects on shared leadership in a team.

Contents

1 Introduction

In several fields, robots are working in teams together with people. Consider disaster control teams, where robots can perform dangerous tasks humans cannot perform because robots have different capabilities or are simply more expendable [Burke et al., 2004, Jung et al., 2013]. We refer to teams that consist of at least one person and at least one robot as **human-robot teams**. An example of a robot in a human-robot team is the packbot, a military bomb disposal robot. The packbot fulfills a role previously performed by a human teammate, namely disposing of a bomb. The soldiers working in a team with the packbot grow attached to the robot. This is indicated by the funerals the soldiers hold for their packbot when it "dies" [Neil, 2013]. By holding a funeral the soldiers show that they have grown attached and that the robot has at least a significant emotional impact on the human members of the team.

The robots that are currently working in human-robot teams are mostly functional robots that have limited social affordances and communicate only with simple non-verbal behaviors, we define them as **minimal robots**. For example, simple non-verbal behaviors could be gaze behaviors that involve only turning the whole body of a robot [Zaga et al., 2017]. In contrast, complex gaze behaviors could mean moving a lot of separate elements, such as turning the body, the head, the eyes and moving the eyelids. Movement is a powerful way of communication, that minimal robots can participate in. People are sensitive to physical movement, including that of abstract shapes which can apply to a minimal, non-anthropomorphic robot [Hoffman and Ju, 2014].

Minimal robots are designed so that they are purely functional for their respective task, without additional features that afford the robot to perform complex communication. As a result minimal robots can be more expendable and cheaper than other robots. Thus the robots in human-robot teams are more likely to be minimal robots. Therefore members of human-robot teams will interact more with minimal robots at work than other kinds of robots.

However, existing minimal robots can use movement communicate and while the non-verbal behaviors of minimal robots are simple, they still have an impact on teams [Jung et al., 2017, Breazeal et al., 2005]. In other words, in human-robot teams, minimal robots will influence the **team dynamics**: "the unconscious, psychological forces that influence the direction of a team's behaviour and performance" [Myers, 2013a, p.1]. This could mean that designers of robot behaviors are unintentionally influencing team dynamics with untested robot behavior designs. For example, a robot interacting with people can have an unintentional ripple effect on human employees in a workplace [Lee et al., 2012]. A ripple effect occurs when an interaction indirectly influences other interactions. Team dynamics influence whether or not that team is successful, effective and productive [Myers, 2013a]. Thus, we have to make sure that a robot is designed in a way that the influence of the robot on the team and its dynamics is positive.

One dynamic that is crucial for task effectiveness is leadership [Carson et al., 2007]. Leadership influences the task outcome of human-human teams significantly [Winston and Patterson, 2006]. Humans have a similar attitude when working together with computers, as when they are working with people [Nass et al., 1996]. Thus, we expect humans to have a similar attitude when working with robots, as when they are working with people. Therefore leadership dynamics are expected to be an important influence in human-robot teams when it comes to task effectiveness and task outcome.

Shared leadership is leadership and responsibility distributed among team members and is useful because it allows for self management and use of the skill of highly experienced professionals in these teams [Pearce and Conger, 2002, Carson et al., 2007]. Shared leadership allows every team member to join in the decision making process and make use of the different capabilities of different team members, including the robot, which could lead to new knowledge or a new view on the situation. The shared responsibility and leadership of shared leadership, could influence the way team members perceive the difficulty of their task. Namely, when more people share in responsibility the burden of an individual leader could be lifted. Shared leadership can also have a positive influence on team performance [Pearce, 2004, Carson et al., 2007] and thus on the objective task performance of the team. We expect the same for human-robot teams. Thus, by supporting shared leadership with a robot we can positively influence human-robot teams.

Shared leadership is facilitated by an internal team environment that consists of three dimensions: shared purpose, social support and voice [Carson et al., 2007]. To have a shared purpose means taking steps to ensure a focus on shared goals. Social support means supporting your teammates, for example through encouragement and recognizing individual and team contributions as well as accomplishment. To have a voice means to participate and give input. These dimensions and shared leadership can be supported by different constructive behaviors [Carson et al., 2007, Balthazard et al., 2004].

There are many constructive behaviors that can support shared leadership, such as encouragement, recognizing contributions and supporting team members. Humans can perform these behaviors, but robots can too. We define **constructive behaviors** as behaviors that are supportive, intended to help or improve [Dictionary, 2018]. Combinations of different constructive behaviors together can make a **constructive interaction pattern**, which can be expressed by a minimal robot. Examples of constructive interaction patterns are an active constructive pattern and a passive constructive pattern. We describe active as taking initiative towards the shared goal of the team and passive as following the team. Thus, when expressing the first interaction pattern a robot would actively contribute and make contact with its teammates. In the second a robot would respond passively to the team and contribute by following orders. We expect that different constructive behavior patterns of a robot influence shared leadership differently.

Currently, robots in a human-robot team environment are not designed with the intent to support shared leadership. However, we think that directed efforts to encourage and establish shared leadership could be made by a robot in a deliberate and constructive way. We currently do not know how robot behaviors in a human-robot team exactly influence shared leadership. We do know that adding a robot to a team or group influences the processes regardless [Lee et al., 2012, Breazeal et al., 2005, Neil, 2013, Jung et al., 2017], so:

- To what degree does the interaction pattern of a robot, (active constructive or passive constructive), influence (i.) shared leadership between teammates (robot and humans), (ii.) objective task performance, and (iii.) perception of task challenge in a team when collaborating towards a shared goal?

In order to answer this question we first need to answer the following:

- How can we design simple non-verbal, constructive, robot interaction patterns (active and passive) to be used in a team setting?

To answer our questions, we designed the active and passive constructive interaction patterns, based on related work (Chapter 2), through iterative design and user tests (Chapter 3). Then we evaluated and validated the interaction patterns (Chapter 4).

We designed an experiment where two participants and a robot execute a collaborative task to test the influence of the different constructive behaviors on shared leadership and tested the

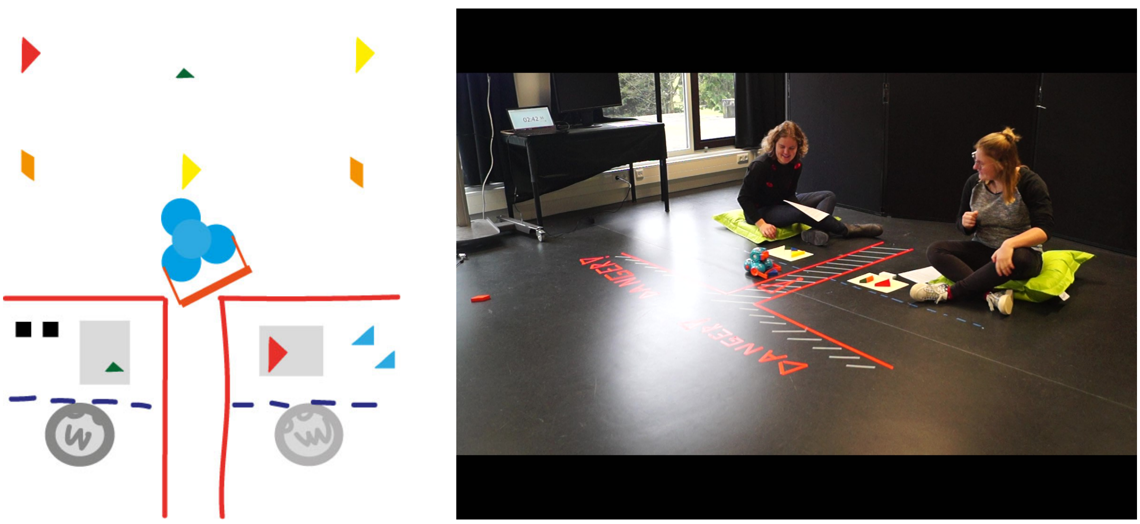


Figure 1: Illustrated top view and a photo of our experiment set-up. We see two human team members and the robot team member performing a puzzle task. the human team members are confined to there seating area. The robot is able to move freely in the danger zone (past the red line), where blocks are located that the human team members need to solve the puzzle. The task is successful when the puzzle is finished

experiment by running a pilot, Figure 1. We then performed the experiment (n = 68). We measured shared leadership by using a questionnaire [Hiller, 2001], objective team performance by measuring the time the team spend on the puzzle and number of correct blocks, and perception of the task challenge by using the NASA Task Load Index [Hart, 1986]. Then we analyzed our collected data, we performed a principal component analysis, anova tests on our quantitative data and t-tests on our qualitative data (Chapter 6). We discuss the results (Chapter 7) an conclude our research (Chapter 8).

We found that validated non-verbal robot behaviors can have unexpected effects, namely not rating the robot differently, but rating your human team mate differently. We also found that a non-verbal robot sharing in shared leadership through voice, does not necessarily increase the voice and shared leadership among human team mates.

This thesis contributes to HRI research by giving insight in designing robot behaviors to support shared leadership in a human-robot team, by showing that non-verbal robot behaviors can have unexpected effects in shared leadership. Furthermore we have shown that a robot having voice or not having voice can influence the voice of human team members in a human-robot team.

2 Background

In this chapter we discuss minimal robots and their place in human-robot teams (Section 2.1), the effects of robots on team dynamics (Section 2.2), shared leadership and the possibilities of a robot sharing in leadership (Section 2.3) and supporting shared leadership by performing constructive interaction patterns (Section 2.4).

Part of the theory we discuss is theory about human-human teams, since we believe that understanding human-human teams will help us understand human-robot teams.

2.1 Minimal Social Robots in Human-Robot Teams

Human-robot teams, teams that consists of at least one person and one robot, are up and coming in many fields. For example in elder care, hospitals, offices, search and rescue, the military and space exploration [Hoffman and Breazeal, 2004].

Every team is a social community, consisting of multiple people who have a shared goal, yet at the same time have a certain role or function [Salas et al., 1992]. This shared goal creates a dynamic between team members, because it creates a dependency between team members necessary to reach the shared goal [Myers, 2013b]. The actions of the team and whether their shared goal is achieved is partially decided by the internal team dynamics.

When people perceive themselves as being part of a team with computers, through perceived interdependence, they display similar attitudes as when working in a team with other people [Nass et al., 1996]. Thus, we expect that humans in a human-robot team will show similar attitudes as members of a human-human team.

In a human-robot team, robots and humans will have to collaborate to reach the shared goal of the team as effectively as possible, similar to human-human teams. Collaboration between robot and human team members will allow human team members to focus on their own specialty, while the robot performs other tasks. This allows the shared goal to be reached as effectively as possible. Collaboration in human-robot teams could be by robot design aimed at the specific goal, since robots designed with specific tasks in mind could be a real addition to a team and perform necessary tasks humans cannot perform.

The tasks of a robot in human-robot teams are dangerous and critical tasks human team members cannot perform. These tasks are also risky to a robot and could damage or destroy the robot. In these scenarios it is useful if robots are easier to replace and easier to repair if something happens to them and they get damaged or destroyed. Thus, adding additional modules that go beyond the functional task, for example modules that support complex expressions, is a risk costwise. Therefore, robots in human-robot teams are functional robots with limited social affordances.

The robots designed to work in human-robot teams are often minimal robots, which are functional and expendable. We define a minimal, social robot as a functional, non-anthropomorphic robot that was designed for a specific task, with limited social affordances. As a result of their limited social affordances the minimal robots in human-robot teams cannot directly mimic human gestures or use speech to make themselves clear. However a minimal robot is able to communicate and interact with people, through non-verbal and low complexity behaviors that are easy to perform [Zaga, 2017]. These non-verbal, low complexity behaviors could be movement behaviors. Movement is more important to the message a robot carries out than robot looks. People are sensitive to movement expressed by abstract objects, such as non-anthropomorphic robots. Robots can communicate through movement, which is critical for conveying dynamic information about the robot. Even more so when there are no anthropomorphic features to extract information from [Hoffman and Ju, 2014].

2.2 Team Dynamics in Human-Robot Teams

Team dynamics in human-human teams are always shifting due to internal and outside influences and have a big impact on the team performance, perception of team mates, and perception of the task. The behavior of one team member can influence the rest of the team members and their performance. That is, disruption caused by one person in a team can be enough to throw off the other team members, and can result in members performing at a lower level than working alone [Rhee et al., 2013].

There are two main disruptive behaviors by individuals in a team that can disrupt team dynamics, namely taking charge and uninvolvement [Hsiung, 2010]. **Taking charge** is described as:

> [...] team members with a taking charge problem do all the work, refuse to let other team members participate, bully other team members, or order other team members around [Hsiung, 2010, p. 1].

Taking charge can involve not letting others take part in the decision making process, which is important for successful shared leadership. Taking charge disrupts the actions and agency of other team members and therefore disrupts the dynamics in a team. **Uninvolvement** also disrupts the team dynamics and is described as:

> [..] team members with an uninvolvement problem work alone, do not attend the team meetings, show no interest in the team's work, refuse to do any work themselves, or attempt to sabotage the team's work. [Hsiung, 2010, p. 1].

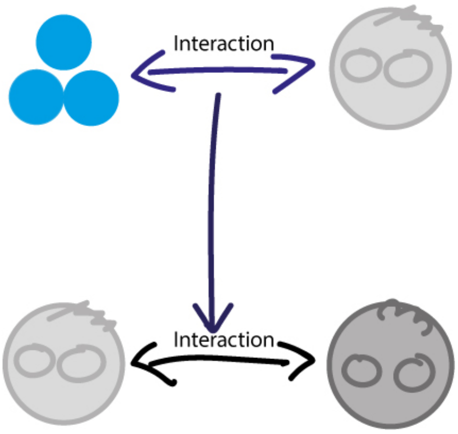


Figure 2: A visualization of the ripple effect in a human-robot team. The interaction between a robot and a human, influences the interactions between the human team mates.

Actions of uninvolvement can lead to exclusion from the team, this includes exclusion from sharing in leadership. Furthermore, excluding yourself from a team and refusing to work puts pressure on the team dynamics and can disturb them. Thus, we can conclude that team dynamics are easily influenced and disrupted by behaviors of individual team members.

We expect that the same holds in human-robot teams, with the added factor of a robot team member, which may communicate differently than human team members. The impact of the packbot (Chapter 1), illustrates that robots in human-robot teams are not merely tools, they are team mates.

We expect that as a member of the team robots can influence team dynamics in a similar way as human team members. Like human team members a robot could also disrupt team dynamics. Therefore, we should explore the effect of robot behaviors on team dynamics carefully. Otherwise, we might end up accidentally designing interaction patterns which influence team dynamics negatively.

Even seemingly small interactions between a robot team member and human team member can influence the team. For example, a robot being present and interacting with colleagues can create a ripple effect in the work environment [Lee et al., 2012]. A ripple effect is when an effect can be followed outwards, for example social interactions that influence situations and other social interactions separate from the initial interaction [Lee et al., 2012], see Figure 2. Thus, a robot interacting with a team member could influence interactions between other team members.

2.3 Robots Sharing in Leadership and Decision Making

In a team there are multiple dynamics at play, one dynamic present in every team is leadership. Leadership is crucial for task effectiveness [Carson et al., 2007]. There are multiple types of leadership, such as hierarchical leadership where a team has a single leader and shared leadership where leadership is shared over two or more leaders. The distributed responsibility of shared leadership creates a dynamic between team members, where they have to lean on each other and trust each other to take their responsibility. It also influences how the team approaches their task; a team with a designated leader may approach the same task differently, than a team where everyone is allowed to lead. For all types of leadership it is important to know what a leader is and what it means to be a leader.

> A leader is one or more people who selects, equips, trains, and influences one or more follower(s) who have diverse gifts, abilities, and skills and focuses the follower(s) to the

> organization's mission and objectives causing the follower(s) to willingly and enthusiastically expend spiritual, emotional, and physical energy in a concerted coordinated effort to achieve the organizational mission and objectives [Winston and Patterson, 2006, p. 7].

Being a sole leader can be a challenging role to fulfill in any team, human-human or human-robot. The kind of leader you are and how well you do your job influences the team dynamics as well as your social position. The official position of leader can be accompanied by the unofficial title of 'tyrant' or 'pushover'. Usually when a team is newly formed, the team has to figure out who is the leader and there might be some contest over who takes up that role. In shared leadership multiple team members fulfill a leadership role.

Shared leadership is an alternative way for teams to be led and could relieve some of the pitfalls of hierarchical leadership. When sharing leadership multiple team members carry responsibilities for finishing their tasks and the overall product. Shared leadership is:

> A dynamic, interactive influence process among individuals in groups for which the objective is to lead one another to the achievement of group or organizational goals or both.... [L]eadership is broadly distributed among a set of individuals instead of centralized in [the] hands of a single individual who acts in the role of a superior. [Pearce and Conger, 2002, p.1]

Shared leadership allows every team member to share responsibility and decision making, while hierarchical leadership does not. Shared leadership can have a positive influence on the perception of team mates and the perception of the task challenge, as everyone is equally responsible for the task and it is not a single person carrying the responsibility for a positive outcome. Shared leadership gives all team members a chance to weigh in on the decision making process. This is especially useful when working in a team of different disciplines where people possess vastly different types and levels of knowledge and skills, since it allows different knowledge of different people to weigh in on the decision. Shared leadership is also a better predictor of team success than hierarchical leadership [Pearce and Manz, 2005] and is beneficial for team performance [Pearce, 2004, Carson et al., 2007]. Thus, shared leadership is a useful type of leadership in a team.

Human-robot teams could benefit from shared leadership, because there is a big difference between the knowledge and skills of the humans and the robot. For example, when there are people of different disciplines and/or multiple types of robots the varying set of skills and disciplines of the different human or robot team members can each be utilized to the fullest if each member gets to share in decision making and leadership. Previously we argued that people behave similarly to being in a team with other people when in a team with a computer [Nass et al., 1996]. Therefore we expect that shared leadership can help in human-robot teams to increase team performance and make new use of the robots capabilities through shared decision making.

2.4 Constructive Interaction Patterns to Support Shared Leadership

Shared leadership can be influenced by several factors and supported by constructive behaviors [Hiller, 2001, Carson et al., 2007], see Figure 3. Shared leadership needs a team environment supported by three dimensions to thrive: shared purpose, social support and voice. Each of these dimensions and shared leadership overall can be supported by constructive behaviors [Carson et al., 2007]. To have a shared purpose means taking steps to ensure a focus on shared goals. Social support means supporting your teammates, for example through encouragement and recognizing individual and team contributions as well as accomplishment. To have a voice means to participate and give input. This includes some constructive behaviors such as: constructive change-oriented communication, participation in decision making and involvement.

Constructive behaviors are not limited to verbal behaviors. An example of a non-verbal constructive behavior is non-verbal encouragement, which humans can perform by cheering or a pat on the back. Non-verbal encouragement in a robot can be a lot simpler, but effective if people recognize the behavior [Gockley and Matarić, 2006]. Non-verbal behaviors can be used to communicate meaningful information and are a type of behavior robots can perform. Non-verbal behavior of a robot in a human-robot team can be used to communicate with human team members and increase task performance [Breazeal et al., 2005]. Thus, we expect that non-verbal constructive behaviors can have a significant effect on individuals and teams.

Full body movement is an example of a non-verbal behavior that can be meaningful and can be performed by a robot. For example by fully turning the body of a robot to position it to look at an object it can become clear that the robot is referencing that object. What the reference means depends on the context. In [Zaga et al., 2017] the robot is trying to help a person with their task by referencing objects. Full body movement is also something a lot of robots can do. The latter is useful if we want to design generalizable minimal robot behaviors that can be used in different human robot teams.

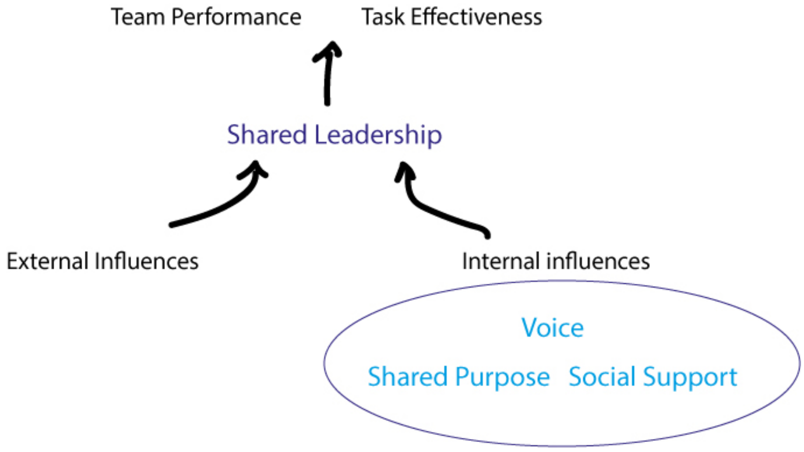


Figure 3: Shared leadership can be influenced by both influences external and internal to the team. Internal influences are voice of the team members, a shared purpose and social support among the team members. In turn shared leadership influences team performance and task effectiveness.

The meaning of robot movements lies in how they are interpreted by humans and be interpreted as constructive is designed as such. For example, a robot that moves systematically towards an object or person could be interpreted as liking said object or person, while a robot driving away at high speed from an object or person might be perceived as being afraid [Levillain et al., 2017]. There are different specific motion cues that trigger psychological interpretations: the spontaneous initiation of a movement, synchronizing in a social interaction, sudden changes in speed or direction, or patterns of approach or avoidance [Levillain et al., 2017], but the way people interpret these behaviors are based on their own biases and experiences. People will also try to interpret the actions of a robot that does not interact with them. Even the actions of a non-social robot using non-verbal behaviors, can still be given meaning by bystanders [Forlizzi, 2007].

There are multiple constructive behaviors, which can be used to build different types of constructive interaction patterns. A constructive interaction pattern can positively influence shared leadership and task effectiveness [Balthazard et al., 2004, Hambley et al., 2007]. Different constructive interaction patterns can influence shared leadership differently. For example one can be constructive by taking the lead, but also by following the team. These are two different constructive actions with different effect on shared leadership; taking a lead can mean sharing in leadership, while following the team means taking a step back in leadership. Thus, shared leadership can be influenced positively by taking the lead and actively sharing in leadership.

Different constructive actions like taking a lead and following a team, translate to active constructive and passive constructive when in an interaction pattern for a robot. In the first a robot would actively contribute and make contact with its teammates. This contributes to voice, one of the three dimensions of shared leadership. Active behavior in a team encourages team members to develop a sense of shared responsibility, key for shared leadership. In a passive constructive interaction pattern a robot would passively follow the team and contribute by following orders only. Passive behavior allows other team members to take the lead. If no one is taking the lead and team members are uninvolved or one person very strongly takes the lead, taking charge over other team members, this could negatively impact shared leadership. Thus we expect that an active constructive interaction pattern has a more positive influence on shared leadership than a passive constructive interaction pattern.

Active and passive constructive interaction patterns could also influence the effectiveness of the team and task performance. We know that passive groups are second in task effectiveness to constructive groups, but above aggressive groups [Hambley et al., 2007]. Therefore, we argue that a robot expressing an active constructive interaction pattern would have a more positive influence on task performance than a robot expressing a passive constructive interaction pattern.

Designing and testing the different interaction patterns would help us figure out how robots can support shared leadership, but also how their interaction patterns are interpreted when working in a team with people.

To conclude, we argue that a minimal robot executing different interaction patterns, active constructive and passive constructive, by using full body movement influences shared leadership and team performance differently depending on the interaction pattern. We expect that an active interaction pattern will have a more positive effect on shared leadership in a human-robot team than a passive interaction pattern.

2.5 Hypothesis

In human-robot teams and human-human teams a shared goal creates a dynamic between team members, because they are dependent on each other in order to reach a shared goal (Section 2.1). Team dynamics are constantly changing, easily influenced or disrupted, have a big impact on the team performance, perception of team mates and perception of task (Section 2.2).

Leadership dynamics are a part of team dynamics and could be influenced by a robot. We argued that a robot sharing in leadership has a positive influence on team performance in human-robot teams (Section 2.3).

Shared leadership, a form of leadership, can be positively influenced by constructive interaction patterns [Balthazard et al., 2004, Hambley et al., 2007]. A constructive interaction pattern can consists of non-verbal robot behaviors (Section 2.4). We can design non-verbal, constructive interaction patterns for a minimal robot, so it can support its team mates (Section 2.1/2.4).

We argued that there is a difference between an active constructive interaction pattern and a passive constructive interaction pattern, where the first has a more positive influence on shared leadership [Hambley et al., 2007], (Section 2.4). In the active constructive interaction pattern the robot actively takes agency of its role in a team and shows behaviors that correspond with having voice [Carson et al., 2007], thus being involved in decision making and leadership. In the passive constructive pattern the robot follows orders from other team mates, not taking initiative and thus not sharing in leadership. We argued that an active constructive interaction pattern also has a positive influence on other team dynamics outside of leadership, namely when it comes to task performance and the perceived task challenge (Section 2.4).

Thus, our hypothesis is: **an active constructive interaction pattern has a more positive influence on (i.) shared leadership between team mates, (ii.) objective task performance and (iii.) the perception of task challenge, than a passive constructive interaction pattern.**

3 Robot Behavior Design

In this section we discuss Dash[1], the robot used for this research, designing the interaction patterns (Section 3.1) and a description of both interaction patterns (Section 3.2).

For our research we needed an off the shelf robot, that can push blocks, which is the key function of the robot in the task that we designed (Chapter 5), and that is easy to control in a Wizard of Oz (WoZ) set-up. Dash by Wonder Workshop, Figure 5, meets all these requirements and has an optional shovel that can be used to push blocks. Thus, we chose to use Dash for our experiment.

Dash can drive around in all directions at a limited speed and by using a shovel can move objects by pushing them. The robot can communicate with other team members, for example when making a suggestion. It will communicate through a single modality for the purpose of this research namely, full body movement. Movement is a powerful way for a robot to communicate, while also being a way a lot of existing robots can communicate (Section 2.1).

Because of its big eye, Dash has a toylike look. This is not entirely fitting for our scenario of disaster control (Chapter 4) where robots look follows their function and generally not toylike. So we covered its eye with lego to make it look less toylike (Figure 4).

The task that we designed is a puzzle task were one robot and two participants collaborate. The puzzle is similar to a tangram puzzle. The participants start off with certain pieces and there are pieces in a danger zone they can not access, which is marked by danger lines. the robot can fetch these pieces for the participants and will during a 20 second cooldown between commands make suggestions in the active condition.

We used a WoZ setup over autonomous behaviors as programming autonomous behaviors is very expensive and time consuming and thus did not fit in the scope of this project.

3.1 Design Process

We designed the robot behaviors through an iterative design process. Iterative design allows us to make multiple design steps and to review, reflect and improve on them. First we made a list of the necessary behaviors for each condition in order to make all the necessary behaviors clear. These behaviors were based on the puzzle, the task of the robot in solving the puzzle and the two interaction patterns. This list consisted of the following behaviors: fetching a block, suggestion behaviors, bringing a block and encouraging behaviors. We brainstormed for multiple movements that could form a behavior for each of these behaviors and in each condition. Then we went through different versions of the behaviors and thought about how they could be interpreted. We did this by acting out the behaviors and making stop motion animations of the behaviors. We used small paper cubes to represent human team members and a small cube robot to push an object. Then we tried the different versions of the behaviors with the cubes with the real robot and picked the most fitting behaviors to create the two interaction patterns[2].

[1] https://uk.makewonder.com/dash/
[2] https://youtu.be/MfI0yAHZP_8

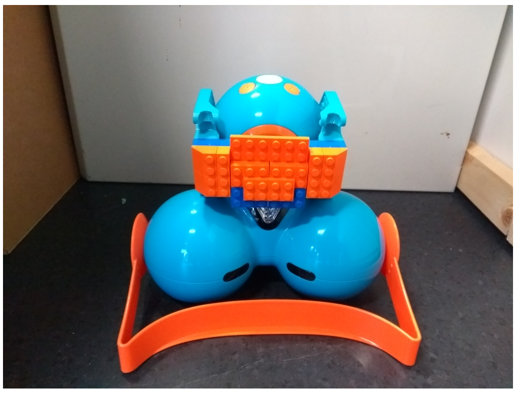


Figure 4: Dash by Wonder Workshop as it was used in our experiment, with a shovel and a lego cover for the eye.

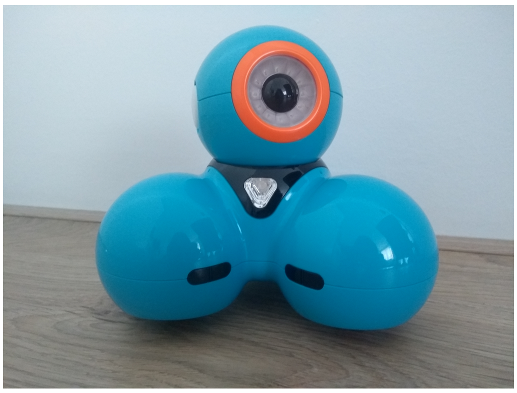


Figure 5: Dash by Wonder Workshop. This is what Dash looks like right out of the box without any additions.

The first versions of the interaction patterns were tested with a volunteer and adjusted afterwards. The same happened for the next version, after which we landed on the final iteration.

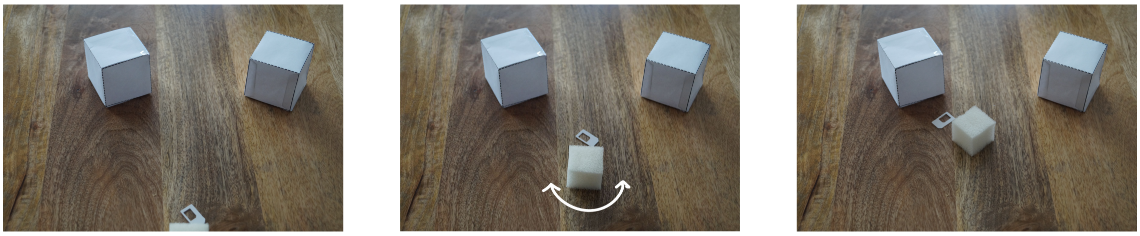


Figure 6: An early version of what a robot bringing a block to human participants could look like.

3.2 Active Constructive and Passive Constructive Behavior Patterns

There are some key interaction moments that change depending on the interaction pattern of the robot, such as sharing an object with team members. We can share objects in different ways; some support shared leadership, some do not. For example, angrily throwing an object at someone is not helpful towards establishing shared leadership. However, sharing an object by pushing it towards someone is helpful can be viewed as constructive behavior.

We built the interaction patterns based on: engagement, effort and enthusiasm. These behavior descriptions fit with active behavior and the opposites distracted, no effort, uninterested fit with passive behavior. The behaviors of a active robot are more engaged, take more effort and show more enthusiasm than the behaviors of a passive robot. An example is speed, doing something speedily shows enthusiasm. Thus, an active robot would be faster than a passive robot.

Both interaction pattern support the team, but an active constructive robot supports the team and provides input, while a passive constructive robot also provides support, but does not provide additional input (Section 2.4). Supportive behavior in a tutor robot includes non-verbal supportive behaviors such as annotating right answers with gestures, nodding and shaking of the head, as well as using gaze behavior to guide the attention of the student [Saerbeck et al., 2010]. We could use these behaviors in our robot with an active or passive constructive behavior pattern, for example we could annotate the right answers in the puzzle, thus making a suggestion. An active constructive robot could make suggestions as to what to do next by gazing at an object or nudging it. It could also use positive reinforcement, such as nodding or shaking when a participant does something correct or participates in the decision making process. Recognizing accomplishments and contributions are constructive behaviors that provide social support, a dimension in shared leadership [Carson et al., 2007]. A further explanation can be found in Section 2.3. In both interaction patterns there would be listening behaviors where the robot follows whoever is talking with its gaze.

3.2.1 Description of the Active Constructive Interaction Pattern

The active constructive interaction pattern contains 7 behaviors. Namely the basic behaviors needed to perform the task and the unique active behaviors mentioned in previously. One of these behaviors is shared with the passive interaction pattern, namely the listening behavior (Figure 1a). All these behaviors together form the active constructive interaction pattern, this see Table 1. There is a 20 second cooldown, for the robot, between following commands from the human team members. The cooldown prevents participants in the experiment from asking for all the blocks in quick succession, not allowing the robot to show all of its different behaviors.

First the robot faces the participants, and stands in between them and the danger line as a starting position. The robot looks at whoever is talking, if no one is talking look at point of shared interest. The robot does this by rotating at a moderate speed (Figure 1a).

When prompted the robot fetches a piece from the danger zone. The robot faces the object away from the participants, then quickly speeds up from still to approach the object. The robot approaches the object in a straight line, then quickly and fully approaches the object (Figure 1b). By bringing the block quickly the robot shows that it is eager to help and responding quickly. The robot pushes the object fast and smoothly towards the participants. It pushes the object towards the participants in a straight line, fully towards the participants. The robot faces the participants while doing so. The robot pushes the object in front of and close to the human team member who requested the object on moderate speed (Figure 1b). By fully pushing the block to the participants the robot takes over as much work from the participants as possible, thus helping as much as it can. The robot offers the object to the participant that asked, unless specified otherwise (bring to him/her).

The robot will encourage human team members by quickly spinning clockwise after a human team member makes a good suggestion (Figure 1j). By encouraging the participants the robot shows support towards the team and the ideas of the participants. When prompted the robot moves a piece between participants. The robot faces the participant who gives the command. Then the robot faces the object, away from the participant, and quickly speeds up from still to approach the object (Figure 1d). The robot then pushes the object fast and smoothly towards the participant who receives the block, in a straight line. The robot pushes the object fully towards the participant and faces the participant while doing so, on moderate speed (Figure 1h). During the cooldown, if there are still blocks left, the robot makes a suggestion. The robot drives to a random block. Stands behind it, facing the participant who needs the block, then nudges the object. The robot does this on moderate speed and until prompted to do something else (Figure 1k). By making suggestions the robot can share in problem solving and thus share in leadership.

3.2.2 Description of the Passive Constructive Interaction Pattern

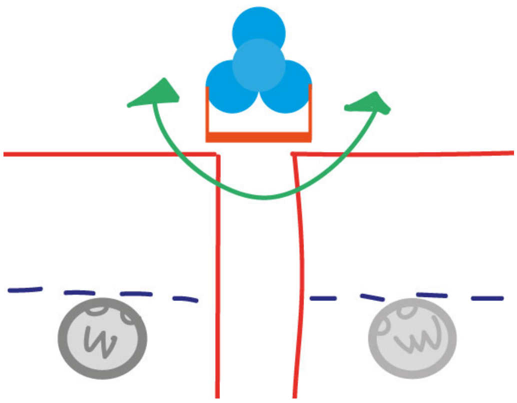
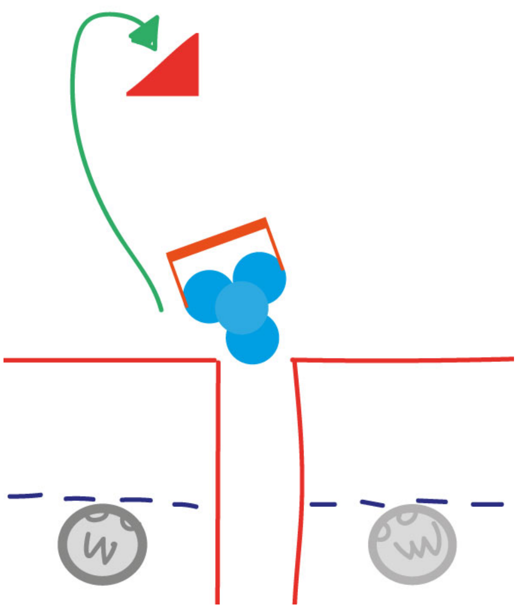
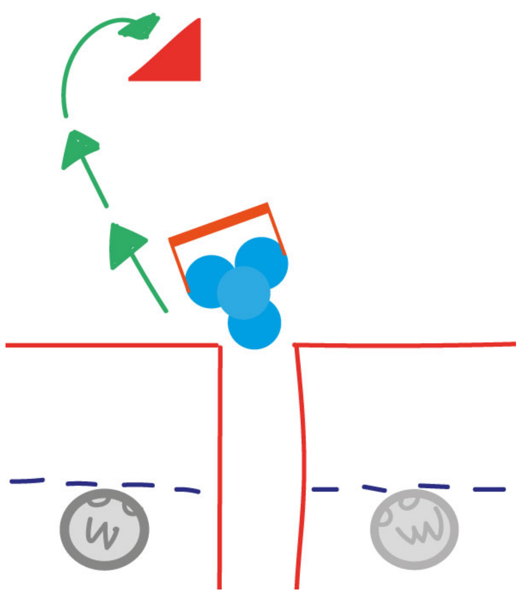
The passive constructive interaction pattern consist of 5 behaviors. Namely the basic behaviors needed to perform the task. Together the behaviors make the passive constructive interaction pattern, which can be viewed in Table 1. Similar to the active constructive interaction pattern, there is a 20 second cooldown between following commands from the participants.

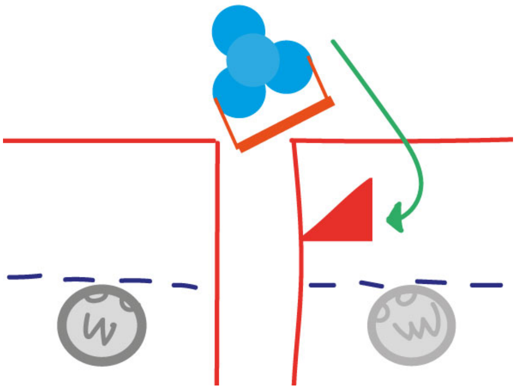
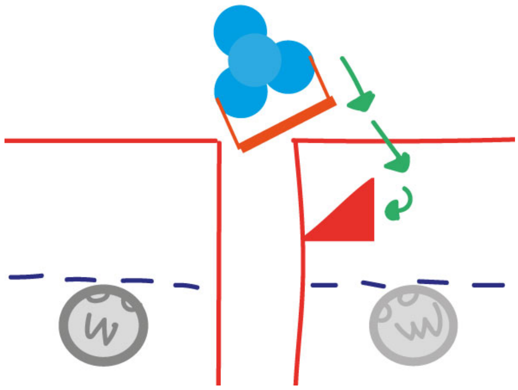
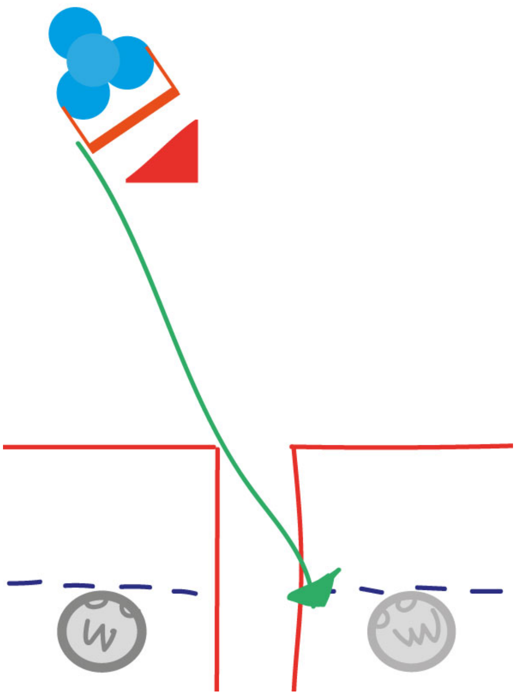
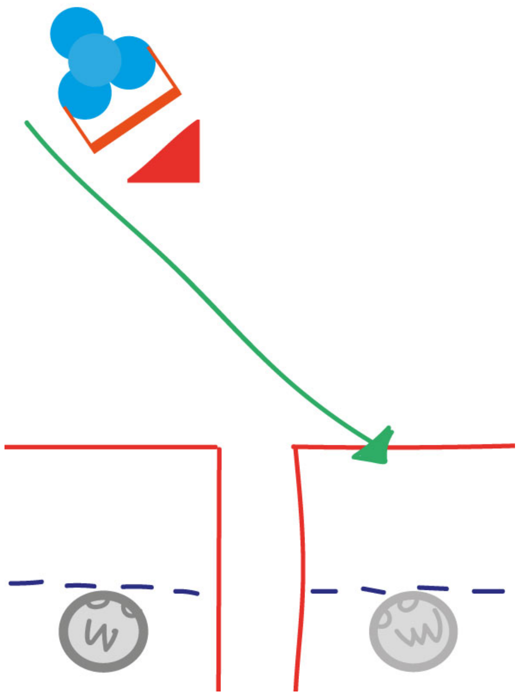
After driving towards the participants the robot should face the participants, and stand in between them and the danger line as a starting position. Then look at whoever is talking, if no one is talking look at point of shared interest, rotate to do so (Figure 1a). This behavior is the same in both interaction patterns.

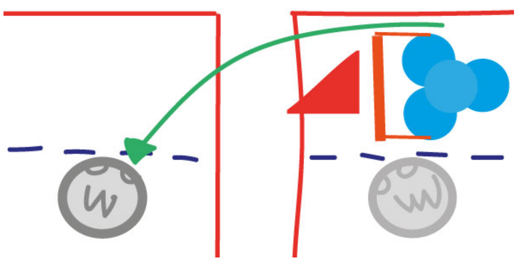
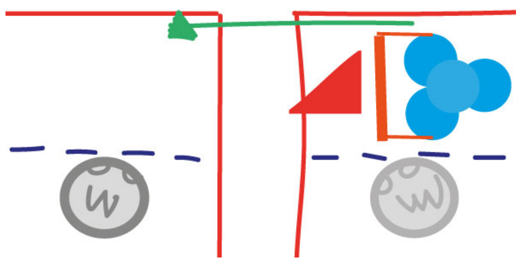
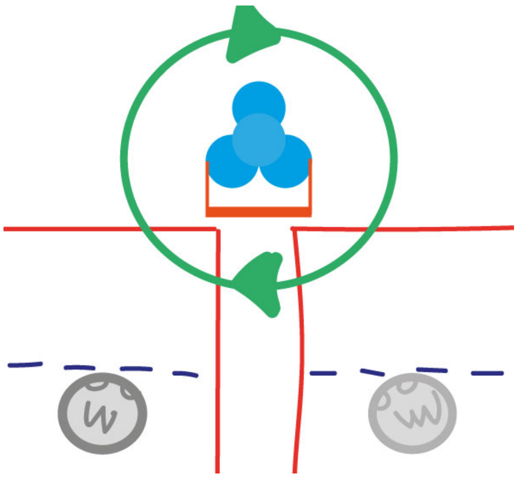
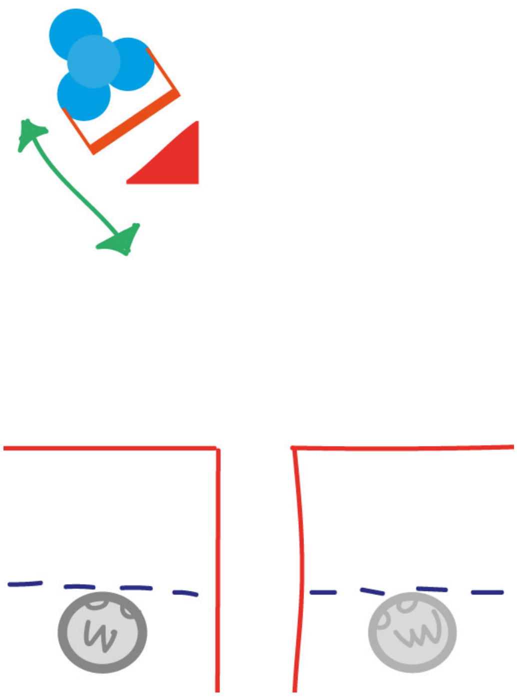
When prompted the robot fetches an object from danger zone. First it faces away from the participants. Then it slowly approaches the object in a straight line. When approaching the block, the robot should do so slowly, with intervals (Figure 1c). The robot parks behind the block for 3 seconds and bring it to the specified location slowly and pushes the block just across the danger zone line, all while facing the participants. The robot offers the object far away from (yet reachable to) the participants (Figure 1g). Human team members can specify where the robot should bring the block (bring it to me, bring it to her/him). If it is not specified where the robot should bring the block, then it will bring the block to whomever issued the order.

When prompted the robot moves a piece between participants. The robot will execute the suggestion slowly. First the robot faces away from the participant who has the object. Then it slowly approaches the object in a straight line (Figure 1e). The robot waits 3 seconds before pushing the object towards the other participant. Then it pushes the object just across the line, at the same height it came from (Figure 1i). Thus, offering the object as far away from participant as possible and not putting in extra effort.

Table 1: Active and passive constructive interaction patterns

Behavior	Active	Passive
Listening	 (a) The robot faces whoever is talking, if no-one is talking it will look at an object of shared interest.	The robot shows the same behavior in the active and passive condition.
Approaching an object/block	 (b) Fetching a block in the active interaction pattern. This is one smooth motion at a medium speed.	 (c) Fetching a block in the passive constructive interaction pattern. The robot moves at a slow speed and makes some short (less than a second) stops before reaching the block.

Behavior	Active	Passive
	 (d) The robot approaches the block near the participant in one smooth motion in the active condition.	 (e) The robot approaches the block near the participant with intervals in the passive condition.
Bringing an object/block	 (f) The robot brings a block in the active constructive interaction pattern and drops it off right next to the participants. Putting in additional effort.	 (g) The robot brings a block in the passive constructive condition and drops it off where participants can reach it.

Behavior	Active	Passive
	 (h) The robot brings a block that is placed at one of the participants in the active constructive interaction pattern. The robot drops the block off right next to the participant, putting in extra effort so the participant doesn't have to.	 (i) The robot brings a block located with one of the participants in the passive constructive interaction pattern. The robot drops the block off at the nearest place where the participant can reach for it.
Encouraging	 (j) Encouraging behavior in the active constructive interaction pattern.	The passive robot performed no encouraging behavior.
Suggesting	 (k) A suggestion made by nudging in the active constructive interaction pattern. the robot makes suggestions during cooldown.	The passive robot didn't make any suggestions. During the cooldown the robot waited while listening to the participants.

4 Robot Behavior Validation

Before we use our interaction patterns in a lab setting we have to validate them. Thus, the goal of this study is to research how both interaction patterns are perceived, as active or passive.

4.1 Method

We held a 2x1 video study, a questionnaire (Appendix A) accompanied by two videos showing the active and the passive interaction patterns to validate the interaction patterns. The videos [3][4] are both approximately 40 seconds in length and show the robot bringing a block to one of two participants present in the video. The participants are solving a puzzle together.

The questionnaire includes questions that participants have to answer after seeing a video with Dash performing one of the interaction patterns while fetching a block for two people solving a puzzle. After answering the first set of questions the participants view another video with Dash performing the same task, but with the other interaction pattern. Thus, the study is a within subject study. The order in which the participants see the different interaction patterns is random.

4.1.1 Manipulation

In the videos we manipulate the constructive robot interaction patterns. Both videos showed the robot being asked to bring a block to two people solving a puzzle, and the robot brining the block. In one case the behavior of the robot behavior matched with the active interaction pattern (Section 3.3.1), in the other the behavior of the robot matched with the passive interaction pattern (Section 3.3.2).

4.1.2 Measure

Our questionnaire consists of open and closed questions. The open questions are there to get an indication of what the participants think about the robot behavior without any input or steering.

We designed a scale of 8 items to research if the interaction patterns were judged as active or passive, see Table 2. These items are likert scales (from 1 = completely disagree to 7 = completely agree) where the participants agree or disagree with a statement, such as: "The robot's behavior is enthusiastic". We made statements related to the whether the robot was engaged or not, enthusiastic or not, if it put in effort or not and two last statements literally asking if the robot was active or passive. We chose the statements as being engaged, enthusiastic and putting in effort are important signs of being an active participant in a team. The scores from the negative questions, such as: "The robot's behavior is uninterested", are flipped and together with the positive items they make a scale rating the perceived level of activeness of the robot behaviors. Scoring high on the scale indicates an active robot.

We also asked questions about the opinion of the participant of the robot as a team member, also on a likert scale. The final section includes demographic questions, asking about age, education level and affinity with robots.

Table 2: Items the scale we designed for validating the active and passive constructive interaction patterns.

Item	Likert scale
The robot's behavior is enthousiastic	1 (Completely disagree) to 7 (Completely agree)
The robot's behavior is uninterested	1 (Completely disagree) to 7 (Completely agree)
The robot's behavior is engaged	1 (Completely disagree) to 7 (Completely agree)
The robot's behavior is distracted	1 (Completely disagree) to 7 (Completely agree)
The robot's behavior shows effort	1 (Completely disagree) to 7 (Completely agree)
The robot's behavior shows no effort	1 (Completely disagree) to 7 (Completely agree)
The robot's behavior is active	1 (Completely disagree) to 7 (Completely agree)
The robot's behavior is passive	1 (Completely disagree) to 7 (Completely agree)

[3] https://www.youtube.com/watch?v=oekwaImZlQw
[4] https://www.youtube.com/watch?v=KAq61QQSjqU

4.1.3 Participants

The study was aimed at all adults with internet access, but most of our participants were students. We found our participants on campus, facebook groups for sharing questionnaires, other websites for sharing questionnaires (surveycircle[5], pollpool[6]) and in personal networks. We held a pilot of n = 20. The total number of participants for this video study is n = 107.

4.1.4 Pilot

We decided to do a data analysis of the early answers to the questionnaire as a pilot. A comparison of means did not show a difference between the two conditions. The open questions suggested that people considered the active robot as sassy. One participant said that the robot only does as told because the humans charge the batteries of the robot. The behavior of the robot coming across as sassy may have caused the participants to show a bit of a dislike towards the robot. We reviewed the videos and changed the behavior in the active interaction pattern where we thought it could be considered sassy. The behavior was the robot returning to the participants after making a suggestion. During this time we also ran a pilot and this behavior did not occur a lot (Section 5.7). We uploaded a new, clearer video with the adjusted behavior, where the robot does not return after making a suggestion. Instead the robot continues making a suggestion until it is told to do otherwise.

4.2 Results

Firstly we explored our data with SPSS and checked for internal consistency before combining any variables, since we designed a scale of matching questions. First we reversed the values of the negatively phrased questions. With both positive and negatively phrased questions we have a scale of 8 different questions in total. We checked the internal consistency of our scale by looking at the alpha of Cronbach of the scale. In the active condition $\alpha = 0.772$, in the passive condition $\alpha = 0.802$.

Based on these results we decided to combine the questions into one scale by taking the mean of the 8 variables. We checked the means and we also checked for normality with the Shapiro-Wilk Test. The data in the passive condition, appears normal (p = .849). The data in the active condition does not (p = .023). We also checked for outliers and there are no extreme outliers.

As the data of one of our conditions is not normally distributed we used the Wilcoxon test. Thus, we also checked our data for symmetry. The data for our passive condition is symmetrical. In the active condition this is not the case, but it is close. We decided to go for the Wilcoxon test, as the alternative, a sign test, does not fit our data.

The Wilcoxon test showed that the active robot interaction pattern was judged significantly more active, engaged, enthusiastic and as putting in more effort than the passive interaction test ($Z = -7.583$, $p > 0.001$). The median for the active condition is 5.38 and 4.25 for the passive condition.

4.3 Discussion and Conclusion

The interaction pattern we designed as active was recognized as more active and the interaction pattern we designed as passive was recognized as more passive by the participants of the questionnaire. Thus, our designed interaction patterns were validated.

An interesting note is that in the first version of our study the active robot was perceived as sassy. A sassy robot was not our goal, as we do not believe a sassy robot to be constructive. It does however show that robot behavior can be interpreted differently than intended and that this can depend on seemingly small behaviors. Thus, we should be careful when designing robot behavior and thoroughly test robot behaviors.

Our scale showed a high inner consistency, thus the items in the scale are measuring the same. The high inner consistency means the scale can be reused to measure whether behavior is active or passive.

A limitation of this study is using the pre-constructed interaction patterns instead of having people rate separate behaviors and then construct the interaction patterns, and then validate

[5]https://www.surveycircle.com/en/
[6]https://www.poll-pool.com/

them. However, we did continuously test the interaction patterns with volunteers during the design process (Chapter 3) and they were validated as active and passive.

For our next study we will be using the validated interaction patterns in a lab setting. Since, our scale showed a high inner consistency we can reuse the scale as a manipulation check in our lab study to see if the interaction patterns are still recognized as active and passive when people interact with the robot themselves, rather than see the robot interact with people on video.

5 Leadership Experiment

Our goal was to find out if a robot can support or share in leadership with minimal behaviors in a human-robot team. In order to research this we conducted a 2x1 in between-subjects study in which we manipulated the interaction pattern of the robot, which was either active constructive or passive constructive. We had a sample size of n = 68. This gives us 34 separate runs of the final test, or 17 pairs for each manipulation where the robot shows either the passive or the active constructive interaction pattern. Our measures are shared leadership, objective task performance, perception of the robot as a teammate and perception of the task challenge.

Figure 7: Puzzle solution, participants start with one correct piece and two additional pieces they have to switch out. The other pieces can be found in the danger zone.

5.1 Task: Requirements

In order to test the influence of the two different minimal interaction patterns on shared leadership two participants have to perform a task with a robot.

Thus, we need a task that further allows for shared leadership and for the robot to have the ability to show the full behaviors during the task. In order for the task to best allow shared leadership we have to create the following circumstances that help shared leadership: a shared purpose [Carson et al., 2007] and the ability of members to participate in the decision-making process [Wood, 2005].

We analyzed games that require shared leadership to reach the success condition (pandemic[7], sand castles[8]), in order to see their common denominators and to further establish what circumstances allow for shared leadership. We found that in these games tasks are distributed by the team, there is a shared goal, everyone is involved in the decision making process and collaboration is necessary to win. The shared goal and members being part of decision making overlap with the previously mentioned theory. Thus, these should be a part of our task, the other common denominators should also be a part of our task, so that the task best allows for shared leadership.

In the active interaction pattern the robot gives suggestion to the human team members, which could influence team decisions. Peers more often influence team members [Pearce and Sims Jr, 2002]. Thus, the robot should be a peer in the task. This way the suggestions of the robot will have the most influence on the team decisions.

5.2 Task: Design

The scenario (Appendix B) establishes both the robot and the two human team mates as a disaster control team who have to collect information from a site after an earthquake, and make the right decision by putting the information together in the right way. The task is a puzzle based task, designed on the requirements in the previous section.

The information is represented by puzzle pieces and the correct way to put it together is represented by the outline on the puzzle paper (Appendix C). The collective task consists of two puzzles made from tangram puzzle pieces. Some puzzle pieces are in a danger zone, unaccessible to the human team members. The danger zone also exists between the human team members, so they cannot physically reach each other and have to use the robot to pass pieces to each other.

The goal of the task for the human team members is to solve the two puzzles as fast as possible with the pieces given to them and pieces that are in the danger zone. The goal of the robot is to help the human team members retrieve the pieces that are unreachable to them and to help solve the puzzle.

The participants start out with one piece in the correct spot, which is also marked on the puzzle paper, and two additional pieces that they have to exchange with the other participant to successfully solve the puzzle. To finish the puzzle the participants need to ask the robot to move

[7] https://boardgamegeek.com/boardgame/30549/pandemic
[8] https://boardgamegeek.com/boardgame/7912/sand-castles

their starting pieces to the other participant and they also have to ask the robot to fetch the pieces from the danger zone and to bring them to the correct person. In between requests there is a cool down period, which means that for 20 seconds the participants cannot ask the robot for any pieces.

The puzzle task was tested and developed with the help of several (unofficial) pilot runs (n = 7) with different people ranging in age from 23 till 57. The final task uses twelve tangram pieces for two puzzles, see Figure 7.

5.3 Manipulation

The modified Dash focuses on promoting shared leadership among the participants and performing its primary function. Dash was controlled by a Wizard of Oz (WoZ). This means that Dash was controlled by a researcher and did not act autonomously. The robot showed two interaction patterns, one passive constructive and one active constructive, in different experimental conditions (Chapter 3).

5.4 Measure

In order to examine if a robot can support shared leadership we need to measure shared leadership, demographics, task performance and perception as well as a manipulation check.

5.4.1 Quantitative Measure

In order to measure shared leadership we needed a validated questionnaire, we used the validated shared leadership questionnaire introduced by [Hiller, 2001]. The questionnaire was originally designed to rate the team as a whole. We wanted to see how both the participants and the robot were judged separately. Thus, we rephrased the statements slightly so that they can be used for each team member individually.

Each participant filled out the shared leadership questionnaire rating both the other participant and the robot. The questionnaire consists of four scales. We only used three: Planning and Organizing, Problem Solving, and Support and Consideration. These three scales can be applied to a team that only meets once. The fourth, Development and Mentoring, is a long term measure. Since our experiment involved working in a team once, this measure is not relevant to our research. In order to objectively measure the task performance of the teams we kept time and stopped the experiment after 10 minutes to prevent the experiment from taking too long. We also checked for the number of pieces that were in the correct spot on the puzzle paper when the time was up. We compared these measures to see if there is a difference in objective task performance. The NASA Task Load Index is a validated and tested measure for the experience of a task and how the task load was perceived. Thus, in order to measure the perception of the task we used the raw NASA Task Load Index [Hart, 1986]. We used the questionnaire we made for the previous experiment as a manipulation check to see if the interaction patterns of the robot were still seen as active and passive.

5.4.2 Qualitative Measure

We collected qualitative data through video and used bottom-up coding to analyze the video. First we freely watched the videos and made note of any notable occurrences. We did this for six videos after which we created an Elan[9] file with tiers on which to notate different occurrences for each video including the first six. We annotated the time spent talking for each participant, saying thank you to the robot for each participant, the robot making suggestions, following robot suggestions for each participant, the first mention of the need to switch starter blocks, when the first block is switched and when the final block is switched.

We annotated giving suggestions for each participant (such as: "could you", "would you", "maybe you need this", "maybe I need this") and if the other participant followed these suggestions (by action or by word). Annotating these was challenging and because of a possible researchers bias we did not analyze these in the end.

The qualitative measure in this study was not validated, as it was somewhat exploratory. We believe that exploring video in this way could lead to interesting additional data. However, our results are mostly based on our quantitative results which we found with validated methods.

[9]https://tla.mpi.nl/tools/tla-tools/elan/

Figure 8: The setup from the perspective of the camera used to film the experiment.

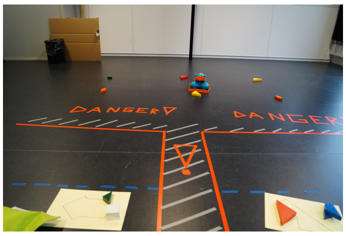


Figure 9: The setup from the perspective of the participants.

Figure 10: The setup from the other side of the two-way mirror.

5.5 Procedure

First the participants were welcomed into the room by a researcher. Each participant was given a consent form (Appendix D) and pen, then the participants were asked to read and sign the form. The researcher asked if they had any questions regarding the consent form. Then the participants were asked to read a task explanation and after any questions they sat down in the task space, while the researcher turned on the camera. The researcher asked a final time if the participants had any questions regarding the task. The participants were told to wait for the robot to start with the task. The researcher left the room with the consent forms and closed the door. The researcher then drove the robot out of its hiding spot, after getting in position behind the two-way mirror. The researcher then performed the robot interaction patterns accordingly (Sections 3.2.1 and 3.3.2). After 10 minutes or if the participants finished the puzzle correctly, the robot returned to its hiding spot and the researcher returned to the task space. The participants were told that they were done and were given the questionnaire to fill out, see Appendix E. The researcher then turned off the camera. The researcher made a picture of their puzzle solution and reset the set-up. After both participants finished the questionnaire, they were debriefed. The researcher thanked the participants for participating and gave them a cookie each. The participants left the room.

5.6 Setup

The set-up was divided over two rooms, see Figure 8 and Figure 10. The rooms share a wall with a two-way mirror. In one room a researcher was present using an Ipad to control the robot. In the other room there were two participants each with their own puzzle and puzzle pieces, divided by a danger zone inaccessible to them. A bit further away was the robot hiding out and more puzzle pieces out of reach from the participants. Figure 9 shows the perspective of the participants. There was also a camera in the corner of the second room.

5.7 Participants

The participants (n = 68) are students and employees of the University of Twente. Their ages vary from 18 to 41 years. Participants were paired in order to participate in the experiment. The participants were approached in the DesignLab in the University of Twente, since some were approached while working in a group some participants did know each other prior to the experiment. However, since participant were randomly assigned to a condition in the experiment this should not influence the results.

5.8 Pilot

We conducted a small pilot with n = 18 people, in 9 pairs, to try out the procedure and the set-up.

We made some small changes to the set-up throughout the pilot. To make it easier to control the robot, we changed orientation of the participants towards the two way mirror. People were cheating when they passed blocks to each other, thus we cleared up what was part of the danger zone by adding additional lines and the writing "DANGER!". Sometimes it was unclear to the participants that their time was up, thus we also made a little hideout for the robot to come out and retreat in after the assignment, instead of bringing it in from the other room. The robot retreating back to its hideout was used as an indication to the participants that the task was over.

During the pilot we found that one of the behaviors was not used. Namely the robot returning to the participants after making a suggestion, if after a set time there is no response from the participants to the suggestion of the robot. Thus we changed so that the robot does not return, but continues making the suggestion, see Chapter 3. This was the biggest change we made to the study.

6 Results

In this section we present our quantitative results; the shared leadership questionnaire, our manipulation check, and the NASA Task Load Index. We also present our qualitative results, which we retrieved by annotating the videos.

6.1 Quantitative results

We set out to research if our hypothesis: "An active constructive interaction pattern has a more positive influence on (i.) shared leadership between team mates, (ii.) objective task performance and (iii.) the perception of task challenge, than a passive constructive interaction pattern", is true. In order to do so we analyzed our the data we received through our measures.

First we explored the data in SPSS, to have an early, quick look. After this we calculated the inner consistency of our scales in the shared leadership constructs and the validation for both both conditions with the alpha of Cronbach, see Table 3. The score of the raw NASA Task Load Index stands out as low. A further look shows very different means in each item. In the active condition the mental demand was high, and the physical demand was low. This makes sense, since participants made a puzzle sitting down. In the passive condition the scores were similar except for effort which was high, this also makes sense as participants had to reach to retrieve puzzle pieces. We decided to still use the NASA Task Load Index regardless as it is a rough indication of the task load. After examining the values of the alpha of Cronbach we combined the separate questions of each scale into one scale each.

Table 3: Internal consistency of the different scales in our questionnaire for both conditions.

Condition	Scale	Items	α
Passive	(Participant) Planning and Organizing	6	0.881
Passive	(Participant) Problem Solving	7	0.923
Passive	(Participant) Support and Consideration	6	0.850
Passive	(Robot) Planning and Organizing	6	0.715
Passive	(Robot) Problem Solving	7	0.772
Passive	(Robot) Support and Consideration	6	0.708
Passive	Validation	8	0.871
Passive	NASA Task Load Index	6	0.110
Active	(Participant) Planning and Organizing	6	0.871
Active	(Participant) Problem Solving	7	0.901
Active	(Participant) Support and Consideration	6	0.861
Active	(Robot) Planning and Organizing	6	0.687
Active	(Robot) Problem Solving	7	0.776
Active	(Robot) Support and Consideration	6	0.638
Active	Validation	8	0.620
Active	NASA Task Load Index	6	0.260

We tested the members of the dyads to determine if we can treat the participants as individuals. A series of Chi-square tests of independence found no significant correlations of the dyads and their ratings, except for the raw NASA Task Load Index ($X(42) = 60.422$, $p = 0.33$). This indicates that one of the puzzles we designed was slightly more challenging than the other. The previous significant difference of the validation holds when analyzing the participants seated on the left only ($n = 32$). The difference for problem solving when rating the other participant is no longer significant ($F(1,30) = 2.892$, $p = 0.99$). Further more we see similar trends in the means when only analyzing the participants on the left. Thus, we made the assumption that we could treat both members of the dyads as individuals.

We performed a principal component analysis, PCA, for the shared leadership questionnaire for both participants rating each other and the participants rating the robot, see Appendix F for the table. We performed the component analysis, because a robot may be judged or rated differently than people. In order to make a fair comparison we need to make sure that the components we use are can be used for both the robot and the participants.

We performed the PCA on both the results for the rating the robot and rating the other participant. We decided to use the components from the PCA when rating the robot. The first component when judging the robot closely matches the problem solving component of the original questionnaire, except for two items which are also strong in other components. The second robot component is similar to the support and consideration component in the shared leadership questionnaire, but lacks some items compared to the support and consideration. Both these components also closely match the component when a PCA is performed on the rating of the participant. There is a clear planning component when looking at the participants, but there no clear planning component when looking at the robot. Thus, the participants seem to rate each other and the robot differently, when it comes to planning. Therefore we used the robot problem solving component and the robot component for support, but we dropped the component for planning.

Then we checked the data for outliers, and went to check the videos to see if something happened during the session of the outlier. We removed the members of one pair as outliers, as one of the participants of the pair came into the experiment with a burnt hand, which may have impacted their ability and feelings regarding the task.

Then we tested for normality of the residuals with a Shapiro Wilkes test, which gives us 4 not normally distributed variables out of 6, see Table 4. We decided to still use an anova test on our data, as it is quite robust.

Table 4: The sigma values of the residuals of our variables after running a Shapiro Wilkes test.

Variable	Sigma
NASA Task Load Index	0.131
Validation	0.003
(Participant) Problem solving	0.016
(Robot) Problem solving	0.001
(Participant) Support and Consideration	0.001
(Robot Support and Consideration)	0.172

We had two significant results, without correction, namely the validation of the active and passive behavior (F (1,62) = 7.130, p = 0.010, mean active = 5.504, mean passive = 4.988, SD active = .645 , SD passive = .908) and the problem solving scale when the participants rate each other (F(1, 62) = 4.265, p = 0.043, n active = 33, n passive = 31, mean active = 5.064, mean passive = 5.609, SD active = 1.053, SD passive = 1.058).

Our non significant results include the participants rating the other participant on shared leadership for support and consideration (F (1,61) = 0.534, p = 0.468, n active = 33, n passive = 30), the participants rating the robot on shared leadership in problem solving (F (1,64) = 2.253, p = .138, n active = 34, n passive = 32) and support and consideration (F(1,64) = 0.052, p = 0.820, n active = 34, n passive = 32). Lastly the NASA Task Load Index (F(1,62) = .736 , p= .394) also gives a non significant result.

The hypothesis: **An active constructive interaction pattern has a more positive influence on (i.) shared leadership between team mates, (ii.) objective task performance (iii.) the perception of robot as a team mate and (iv.) the perception of task challenge, than a passive constructive interaction pattern**, is rejected.

6.2 Qualitative results

The qualitative results have less data points since participants were treated as a pair, thus we performed a t-test. We performed a t-test on the following: how often participants said thank you, when exchanging the first block was mentioned and how much the participants are talking. We do not have a time stamp for people who mentioned exchanging the block before the experiment started and people never mentioning it during the experiment. Manually assigning them a minimal or maximal value such as zero or ten minutes could skew the results. Thus, we removed them as outliers. Since how much an individual talks is partly based on how much their conversation partner talks, we took the amount of time the participants were talking (in milliseconds) divided by how long the experiment took and added them, so the participants were reviewed as a dyad.

No significant difference was found in when the participants mention switching the first block (t(23) = -.274, p = .786, n active = 13, n passive = 12) or saying thank you (t(60) = -.807, p = .423, n active = 32, n passive = 30).

A significant difference was found between the two conditions for the amount of time groups spent talking, according to our data active groups talk more ($t(24,443) = -2.315$, $p = 0.029$, n active = 16, n passive = 16, mean active = .405, mean passive = .335 , SD active = .105, SD passive = .062).

7 Discussion

We set out to investigate to what degree a minimal robot interaction pattern influences shared leadership, between the robot and human team mates and between the human team mates. In order to achieve this we designed two different robot interaction patterns with minimal, non-verbal behaviors, one active constructive and one passive constructive. Then we validated the interaction patterns with a video study (n = 107). We also designed an experiment where two participants have to solve a joint tangram-based task together with Dash, a minimal robot. We measured shared leadership, cognitive task load and perception of the robot as active or passive.

We hypothesize that the active robot interaction pattern allows the robot to share in decision making, which is key to shared leadership. Active behavior in a team encourages team members to develop a sense of shared responsibility, which helps social support, the second dimension of shared leadership [Carson et al., 2007]. Thus, we expected that an active interaction pattern would have a more positive effect on shared leadership and task performance than a passive interaction pattern.

Yet, participants rated the other participant as more effective in problem solving in the passive condition. The participants talked more in the active condition than in the passive condition. The robot was not rated differently in either condition. This is interesting as the robot is the one whose behavior we manipulated. Thus, the change of interaction patterns of the robot influenced the behavior of the participants to such a degree that it was noticed by the other participants. The different interaction patterns were still recognized as active and passive.

Against our expectations we did not find any indication that an active constructive interaction pattern has a more positive influence than a passive constructive interaction pattern on shared leadership, the perception of the robot as a team member, the objective task performance and the task challenge. Thus, our validated interaction patterns did not have the expected effects. Nonetheless, it is clear that the robot interaction patterns have an effect on shared leadership between the human team members, and the shared leadership between the robot and the human team members.

The active robot interaction pattern includes giving suggestions and encouragement to other team members, therefore the robot has input in the way the team carries out its purpose. The previous is a description of having voice, a dimension of shared leadership. Thus this indicates that the robot has voice in the active condition. Voice can support shared leadership and is associated with multiple behaviors that can result in increased involvement [Carson et al., 2007]. Therefore we think that the robot can influence shared leadership through voice, and by having a voice the robot is involved in the decision making process.

The robot being more involved in the active condition inspires the participants to be more involved as well. We can see this by the increased amount of talking of the participants in the active condition. Another reason for increased talking could be a higher perceived difficulty of the task. However there was no difference found in the NASA task load index to indicate that the participants in the active condition found the task harder than the participants in the passive condition. Thus that is not the reason for the increased talking.

Increased talking and thus the participants being more involved in the active condition could be the result of a ripple effect, where the robot being involved causes the participants to be more involved. A robot can create a ripple effect, where the ripple effect affects people in the immediate surroundings of the robot [Lee et al., 2012].

The robot having voice and improving involvement in the team, indicates that the robot is part of the shared leadership process. Yet, the robot in the active condition does not seem to support shared leadership between participants. This is underlined by our other result. Namely, we saw that participants rated each other higher on problem solving in the passive condition than in the active condition. In the active condition the robot is doing problem solving by making suggestions. As the robot takes over part of this task there is less problem solving for each participant to do, thus the lower rating. This causes us to consider the possibility that the robot having voice, reduces the voice of the participants in the team.

Team dynamics are easily influenced or disrupted [Rhee et al., 2013, Hsiung, 2010]. Disruption caused by one person in a team can be enough to throw off the other team members and can result in members performing at a lower level than working alone [Rhee et al., 2013]. It could be that the robot in the active constructive condition shows one of the two main disruptive behaviors, namely taking charge. Taking charge is described as: team members with a taking charge problem do all the work, refuse to let other team members participate, bully other team members, or order other

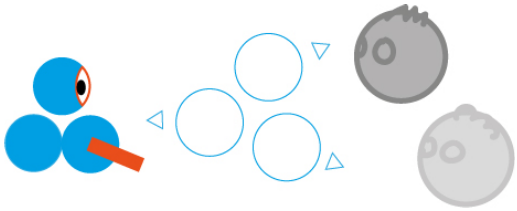


Figure 11: The robot has voice, thus the robot is sharing in the decision making. The robot and the participants have input on how to proceed.

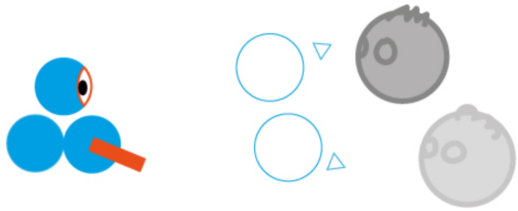


Figure 12: In the passive condition the robot has no voice, thus the participants are the only ones who have input on how to proceed towards the goal.

members around [Hsiung, 2010]. The robot suggesting puzzle pieces in the active condition could meet two of the taking charge criteria: doing all the work and order other members around.

The robot taking charge could reflect back on the other team members and result in them performing at a lower level. Namely by taking charge, through expressing its voice the robot reduces the voice of the participants. Another possibility is that rather than being a disruption by taking charge the robot is simply an additional team member taking part in the shared leadership and having a voice in a team that has a set assignment. This is supported by the statements that humans accept robot autonomy in the interest of the team [Schermerhorn and Scheutz, 2009] and people do not mind giving decision making control to the robot [Gombolay et al., 2015]. Thus the robot having voice creates a second ripple effect where, by adding a voice, the other voices have less space, see Figure 11 and Figure 12. This could explain the difference in the problem solving rating of the participants.

The active robot encourages more involvement of the participants by being involved itself, but this involvement does not lead to more voice for the participants, just to more voice for the robot. Thus, the robot is part of the shared leadership, but the part that participants have in shared leadership is smaller than in the passive condition where the robot does not have voice. The human team members having a lesser part in shared leadership is an unexpected effects of our validated interaction pattern.

7.1 Limitations

Limitations of the study include the scenario, an assignment for a disaster control team, which is quite specific. Therefore we do not know to what degree the scenario is generally applicable. The scenario does however force team play which is necessary for the participants to feel like they were part of a team. This allowed us to test the effect the different robot interaction patterns had on teams.

We validated the interaction patterns by creating two and testing them, rather than testing different behaviors and using those to create the interaction patterns. The latter method could have resulted in different interaction patterns. However our interaction patterns were validated through the video study and then were once again recognized by participants in the experiment.

We used Dash to perform the interaction patterns, as it is an off the shelf robot that can push objects and is easy to control. The latter allows us to properly repeat behaviors, without having to program a robot. However, Dash has a toylike look, which could positively bias people towards it. Dash being toylike does not limit the generalizability of the study. Many other social robots, like Nao, are also toylike. Thus, the effect of a possible positive bias is limited.

The shared leadership questionnaire relied on self reporting, but it was validated and not the only measure. What could have given us a bit more insight would be to have people rate themselves, not just their teammates and the robot. This was however an afterthought. While a longer questionnaire could have provided more data, the data we collected was sufficient for answering our research question and hypothesis. An important reason to use this questionnaire was that is is validated and no shared leadership questionnaire for robots was found.

The NASA Task Load Index scored low on internal consistency, when we analyzed our data. This indicates that the NASA Task Load index may not be the best way to measure task load in studies were the task has a high mental load, but a low physical load.

7.2 Future work

Future work could focus on different aspects or dimensions of shared leadership and how to support those with non-verbal behaviors, as well as if it is better for a robot to be part of the shared leadership or just support it, especially when we look at the effects on human team members. In our case the voice of the robot reduced the voice of the participants. Whether this is desirable may be dependent on the task and the knowledge and skill of the human team members. Thus, we could research when a robot should use voice or take charge.

However the robot taking a lead and also encouraged participants to be more involved. We feel this could be be further explored and supported with a study that explores whether people follow robot suggestions and suggestions of each other more when a robot shows involved behaviors in a human-robot team.

A robot taking charge or expressing voice requires some autonomy. Robot autonomy can affect a human-robot team and the collaboration between team members. It would also be interesting to research what a robot taking charge means for a human-robot team and if a robot taking charge means something else than a human taking charge, especially in the context of shared leadership and human-robot teams. The same goes for having voice.

One of our findings is that the robot is rated differently on planning in the shared leadership questionnaire than people. It could be useful to find out where exactly this difference is and to develop a questionnaire for robots, for future research of shared leadership in human-robot teams.

8 Conclusion

We set out to answer whether an active had a more positive influence on shared leadership than a passive interaction pattern. In order to research this we designed (Chapter 3) and validated (Chapter 4) active and passive constructive interaction patterns. We also designed and conducted a 2x1 study (Chapter 5), where two participants collaborated in a human-robot team with the robot showing one of the two interaction patterns. We analyzed the data and presented the results (Chapter 6).

Our validated interaction patterns had a different effect than expected. Namely, the active constructive interaction pattern did not have a more positive effect on shared leadership than the passive constructive interaction pattern. The active robot creates more involvement of the participants by being involved itself, but this involvement does not lead to more voice for the participants, just to more voice for the robot. Thus the robot seems to be part of the shared leadership, but the participants part in the shared leadership is smaller, than in the passive condition where the robot does not have voice.

We learned about robots in teams, specifically that the influence of non-verbal robot behaviors on a team can be more complex than initially anticipated. The interaction patterns we designed and validated had a different effect on the team than anticipated (Chapter 6). Namely the robot had a ripple effect on the human team members, were they rated each other more positively on problem solving in the passive condition and talked more in the active condition.

In high stress scenarios unintentional effects of a robot on team and leadership dynamics can have heavy consequences in human robot teams, which can be dangerous in certain scenarios where human lives depend on the effectiveness of the team for example in search and rescue [Burke et al., 2004, Jung et al., 2013]. Less extreme consequences could also occur, such as team members disliking each other. Thus, we should be careful in designing robot behaviors.

This thesis contributes to HRI research by giving insight in design implications, on how to design robot behaviors to allow a robot to share in leadership in a human-robot team and contributes by providing insight in how non-verbal robot interaction patterns influence human team members in a human-robot team, through a ripple effect.

Shared leadership in a human-robot team allows a robot to share its knowledge with human team members and could allow the human members of the team to focus on other tasks to improve team performance and efficiency. Thus, shared leadership in human-robot teams is interesting and helpful. The unexpected results found in our research show that it is important to research robot behaviors to support human-robot teams before implementing them.

References

[Balthazard et al., 2004] Balthazard, P., Waldman, D., Howell, J., and Atwater, L. (2004). Shared leadership and group interaction styles in problem-solving virtual teams. In *System Sciences, 2004. Proceedings of the 37th Annual Hawaii International Conference on*, pages 11–21. IEEE.

[Breazeal et al., 2005] Breazeal, C., Kidd, C. D., Thomaz, A. L., Hoffman, G., and Berlin, M. (2005). Effects of nonverbal communication on efficiency and robustness in human-robot teamwork. In *Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on*, pages 708–713. IEEE.

[Burke et al., 2004] Burke, J. L., Murphy, R. R., Coovert, M. D., and Riddle, D. L. (2004). Moonlight in Miami: Field study of human-robot interaction in the context of an urban search and rescue disaster response training exercise. *Human–Computer Interaction*, 19(1-2):85–116.

[Carson et al., 2007] Carson, J. B., Tesluk, P. E., and Marrone, J. A. (2007). Shared leadership in teams: An investigation of antecedent conditions and performance. *Academy of management Journal*, 50(5):1217–1234.

[Dictionary, 2018] Dictionary, C. (2018). Meaning of "constructive" in the english dictionary. Available at https://dictionary.cambridge.org/dictionary/english/constructive#dataset-british, Last acessed at: 12-06-2018.

[Forlizzi, 2007] Forlizzi, J. (2007). How robotic products become social products: an ethnographic study of cleaning in the home. In *Proceedings of the ACM/IEEE international conference on Human-robot interaction*, pages 129–136. ACM.

[Gockley and Matarić, 2006] Gockley, R. and Matarić, M. J. (2006). Encouraging physical therapy compliance with a hands-off mobile robot. In *Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*, pages 150–155. ACM.

[Gombolay et al., 2015] Gombolay, M. C., Gutierrez, R. A., Clarke, S. G., Sturla, G. F., and Shah, J. A. (2015). Decision-making authority, team efficiency and human worker satisfaction in mixed human–robot teams. *Autonomous Robots*, 39(3):293–312.

[Hambley et al., 2007] Hambley, L. A., O'Neill, T. A., and Kline, T. J. (2007). Virtual team leadership: The effects of leadership style and communication medium on team interaction styles and outcomes. *Organizational behavior and human decision processes*, 103(1):1–20.

[Hart, 1986] Hart, S. G. (1986). NASA Task Load Index (TLX). volume 1.0; paper and pencil package.

[Hiller, 2001] Hiller, N. J. (2001). *Understanding and measuring shared leadership in work teams.* PhD thesis, Pennsylvania State University.

[Hoffman and Breazeal, 2004] Hoffman, G. and Breazeal, C. (2004). Collaboration in human-robot teams. In *Proc. of the AIAA 1st Intelligent Systems Technical Conference, Chicago, IL, USA*.

[Hoffman and Ju, 2014] Hoffman, G. and Ju, W. (2014). Designing robots with movement in mind. *Journal of Human-Robot Interaction*, 3(1):89–122.

[Hsiung, 2010] Hsiung, C.-M. (2010). Identification of dysfunctional cooperative learning teams based on students' academic achievement. *Journal of Engineering Education*, 99(1):45–54.

[Jung et al., 2017] Jung, M. F., Beane, M., Forlizzi, J., Murphy, R., and Vertesi, J. (2017). Robots in group context: Rethinking design, development and deployment. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, pages 1283–1288. ACM.

[Jung et al., 2013] Jung, M. F., Lee, J. J., DePalma, N., Adalgeirsson, S. O., Hinds, P. J., and Breazeal, C. (2013). Engaging robots: easing complex human-robot teamwork using backchanneling. In *Proceedings of the 2013 conference on Computer supported cooperative work*, pages 1555–1566. ACM.

[Lee et al., 2012] Lee, M. K., Kiesler, S., Forlizzi, J., and Rybski, P. (2012). Ripple effects of an embedded social agent: a field study of a social robot in the workplace. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 695–704. ACM.

[Levillain et al., 2017] Levillain, F., Zibetti, E., and Lefort, S. (2017). Interacting with non-anthropomorphic robotic artworks and interpreting their behaviour. *International Journal of Social Robotics*, 9(1):141–161.

[Myers, 2013a] Myers, S. P. (2013a). Definition of team dynamics. Available at http://www.teamtechnology.co.uk/team/dynamics/definition/, Last acessed at: 19-05-2018.

[Myers, 2013b] Myers, S. P. (2013b). The difference between team and group dynamics. Available at http://www.teamtechnology.co.uk/team/dynamics/vs-group-dynamics/, Last acessed at: 19-05-2018.

[Nass et al., 1996] Nass, C., Fogg, B., and Moon, Y. (1996). Can computers be teammates? *International Journal of Human-Computer Studies*, 45(6):669–678.

[Neil, 2013] Neil, M. (2013). Are soldiers getting too emotionally attached to war robots? Available at https://motherboard.vice.com/en_us/article/jppy8g/are-soldiers-getting-too-emotionally-attached-to-war-robots, Last acessed at: 19-05-2018.

[Pearce, 2004] Pearce, C. L. (2004). The future of leadership: Combining vertical and shared leadership to transform knowledge work. *The Academy of Management Executive*, 18(1):47–57.

[Pearce and Conger, 2002] Pearce, C. L. and Conger, J. A. (2002). *Shared leadership: Reframing the hows and whys of leadership*. Sage.

[Pearce and Manz, 2005] Pearce, C. L. and Manz, C. C. (2005). The new silver bullets of leadership: The importance of self-and shared leadership in knowledge work. *Organizational Dynamics*, 34(2):130–140.

[Pearce and Sims Jr, 2002] Pearce, C. L. and Sims Jr, H. P. (2002). Vertical versus shared leadership as predictors of the effectiveness of change management teams: An examination of aversive, directive, transactional, transformational, and empowering leader behaviors. *Group dynamics: Theory, research, and practice*, 6(2):172.

[Rhee et al., 2013] Rhee, J., Parent, D., and Basu, A. (2013). The influence of personality and ability on undergraduate teamwork and team performance. *SpringerPlus*, 2(1):16.

[Saerbeck et al., 2010] Saerbeck, M., Schut, T., Bartneck, C., and Janse, M. (2010). Expressive robots in education - varying the degree of social supportive behavior of a robotic tutor. In *28th ACM Conference on Human Factors in Computing Systems (CHI2010)*, pages 1613–1622, Atlanta. ACM.

[Salas et al., 1992] Salas, E., Dickinson, T. L., Converse, S. A., and Tannenbaum, S. I. (1992). Toward an understanding of team performance and training. *Teams: Their training and performance*, pages 3–29.

[Schermerhorn and Scheutz, 2009] Schermerhorn, P. and Scheutz, M. (2009). Dynamic robot autonomy: Investigating the effects of robot decision-making in a human-robot team task. In *Proceedings of the 2009 international conference on multimodal interfaces*, pages 63–70. ACM.

[Winston and Patterson, 2006] Winston, B. E. and Patterson, K. (2006). An integrative definition of leadership. *International journal of leadership studies*, 1(2):6–66.

[Wood, 2005] Wood, M. S. (2005). Determinants of shared leadership in management teams. *International Journal of Leadership Studies*, 1(1):64–85.

[Zaga, 2017] Zaga, C. (2017). Something in the way it moves and beeps: Exploring minimal nonverbal robot behavior for child-robot interaction. In *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*, pages 387–388. ACM.

[Zaga et al., 2017] Zaga, C., de Vries, R. A., Li, J., Truong, K. P., and Evers, V. (2017). A simple nod of the head: The effect of minimal robot movements on children's perception of a low-anthropomorphic robot. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, pages 336–341. ACM.

Appendices

A Ethics Form and Questionnaire Behavior Validation

Robot Behavior

* Required

Consent

The University of Twente and the Department of EEMCS support the practice of protecting research participants' rights. Accordingly, this project was reviewed and approved by an Institutional Ethical Board. The information in this consent form is provided so that you can decide whether you wish to participate in our study. It is important that you understand that your participation is considered voluntary. This means that even if you agree to participate you are free to withdraw from the experiment at any time, without penalty.

The goal of this research is to collect data on how certain robot behaviors are interpreted. This data is anonymous and will be used to validate and further develop robot behaviors. The data can be shared amongst researchers that are part of this study. This study is carried out as a part of a master thesis in the Human Media Interaction program at the University of Twente and the data will be described in said master thesis.

For this study you will watch a video of two people interacting with a robot, after which you will fill out a questionnaire with questions regarding the robot's behavior. This will take approximately 10 minutes. If you have any questions regarding this research please send an email to: j.weda@student.utwente.nl

Contact information:

Judith Weda Bsc
Jered Vroon Msc
Cristina Zaga Msc
Dr. Mariet Theune

Human Media Interaction group
Drienerlolaan 5
7522 NB Enschede
The Netherlands
http://hmi.ewi.utwente.nl/
053-4893740 (Secretary)

j.weda@student.utwente.nl

If you are 18 or older, you want to participate in this study and you agree to all the conditions above, please agree below:

1. **Have you read all of the above and do consent to participate in this survey?** *

   Mark only one oval.

   - Yes, I consent
   - No, leave this survey *Stop filling out this form.*

Robot Behavior - Open Questions

Robot Behavior

http://youtube.com/watch?v=KAq61QQSjqU

This video shows a disaster control team performing a task together. They are on site in an environment with a simulated disaster. The team exists out of a robot and two experts in disaster control. The actual disaster area is dangerous and therefore a risk to humans. The robot team member can access this area and retrieve information for the team. The information is represented by puzzle pieces and the situation can be solved by the team by correctly placing the pieces and solving the puzzle. In the video you see the robot retrieving a puzzle piece for the team. This video has no sound.

2. **What does the robot do?** *

3. **With what attitude is the robot performing its task?** *

4. **What do you think the goals of the robot are?** *

5. **What do you think the robot wants from the people in the video?** *

Robot Behavior - Scale

Agree or disagree with certain statements.

6. **The robot's behavior is enthousiastic.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

7. **The robot's behavior is uninterested.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

8. **The robot's behavior is engaged.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

9. **The robot's behavior is distracted.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

10. **The robot's behavior shows effort.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

11. **The robot's behavior shows no effort.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

12. **The robot's behavior is constructive.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

13. **The robot's behavior is destructive.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

14. **The robot's behavior is active.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

15. **The robot's behavior is passive.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

Robot Behavior - Team

16. **The robot is an essential part of the team.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

17. **The robot is a helpful team member.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

18. **Would you like this robot to be in your team?** *
Mark only one oval.

⬭ Yes
⬭ No

19. **Why? / Why not?** *

____

____

____

____

____

20. **Did the robot make a suggestion? Why do you think so?** *

____

____

____

____

____

Robot Behavior

21. **Did someone control the robot?** *

Mark only one oval.

- ◯ No, the robot is autonomous.
- ◯ Yes, the person on the left controlled the robot.
- ◯ Yes, the person on the right controlled the robot.
- ◯ Yes, the robot was controlled by a third person off screen.

Robot Behavior - Open Questions

Robot Behavior

http://youtube.com/watch?v=oekwaImZIQw
This video shows a disaster control team performing a task together. They are on site in an environment with a simulated disaster. The team exists out of a robot and two experts in disaster control. The actual disaster area is dangerous and therefore a risk to humans. The robot team member can access this area and retrieve information for the team. The information is represented by puzzle pieces and the situation can be solved by the team by correctly placing the pieces and solving the puzzle. In the video you see the robot retrieving a puzzle piece for the team. This video has no sound.

22. **What does the robot do?** *

23. **With what attitude is the robot performing its task?** *

24. **What do you think the goals of the robot are?** *

25. **What do you think the robot wants from the people in the video?** *

Robot Behavior - Scale

Agree or disagree with certain statements.

26. **The robot's behavior is enthousiastic.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

27. **The robot's behavior is uninterested.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

28. **The robot's behavior is engaged.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

29. **The robot's behavior is distracted.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

30. **The robot's behavior shows effort.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

31. **The robot's behavior shows no effort.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

32. **The robot's behavior is constructive.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

33. **The robot's behavior is destructive.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

34. **The robot's behavior is active.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

35. **The robot's behavior is passive.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

Robot Behavior - Team

36. **The robot is an essential part of the team.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

37. **The robot is a helpful team member.** *
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

38. **Would you like this robot to be in your team?** *
Mark only one oval.

⬭ Yes
⬭ No

39. **Why? / Why not?** *

40. **Did the robot make a suggestion? Why do you think so?** *

Robot Behavior

41. **Did someone control the robot?** *
Mark only one oval.

- No, the robot is autonomous.
- Yes, the person on the left controlled the robot.
- Yes, the person on the right controlled the robot.
- Yes, the robot was controlled by a third person off screen.

Demographics

42. **What is your gender?** *
Mark only one oval.

- Male
- Female
- Other

43. **What is your age?** *
Mark only one oval.

- 18-25
- 26-35
- 36-45
- 46-55
- 56-65
- 65+

44. **What is the highest level of education you finished?** *

Mark only one oval.

- Bachelors
- Masters
- High school
- Trade school
- PhD/MD
- Elementary school
- Associates degree
- Other: ______________________

45. **On a scale of 1 to 10, how would you rate your affinity with robots?** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
No affinity											High affinity

Powered by Google Forms

B Task Explanation

Task Explanation

You are a disaster control team on site after an earthquake. In order to get the proper help on site for this disaster you have to collect information off the site and put it together in the right order. Most of this information is in a place you cannot reach as the area is too dangerous. Therefore you have a robot team mate who is already on the site and can access the danger zone to retrieve this information for you.

The goal of this task is to solve the two puzzles you have in front of you. Both puzzles need to be solved to successfully finish this task. In order to do this you have to collaborate together. Both of you start out with a number of pieces and one piece in the correct spot, this is marked on the puzzle paper. The other pieces may or may not belong to you. Both puzzles can be solved with the pieces available to you! There will also be several pieces in a field that you can not reach. The robot can reach the pieces in the field and would be able to bring pieces from you to the other team mate or from your other team mate to you. The robot can only move one piece at a time, once every 20 seconds, after fetching a piece the robot needs to cooldown. When asked to move a piece during the cooldown the robot will back-up and shake it's head. This behavior will also occur when the robot is asked something it cannot do.

You can tell the robot to fetch a piece by pointing at the piece and describing its looks and position. Please be clear in your communication with the robot and repeat yourself if you feel the robot didn't understand you. An example of a clear command is: "Fetch the yellow triangle on the left". You can indicate who the robot should bring the piece to with words such as "me", "him", "her". You can also put a piece in front of you and ask the robot to bring it to the other person.

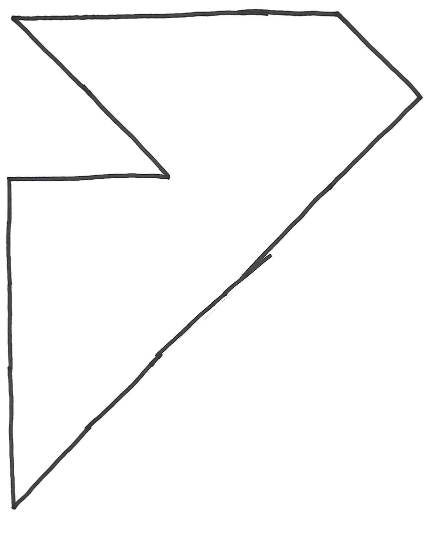
You cannot touch your teammates pieces or directly give them to them, as you are not allowed to leave your spot or cross the danger zone.

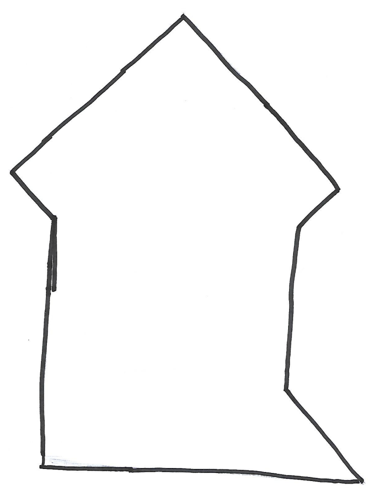
You are allowed to talk and discuss.

Solve the puzzles as quickly as possible.

The task is over when you solve the puzzle or when otherwise indicated.

C Puzzle Outline





D Ethics Form Main Study

Consent Form **Group number:** **Participant Number:**

The University of Twente and the Department of EEMCS support the practice of protecting research participants' rights. Accordingly, this project was reviewed and approved by an Institutional Ethical Board. The information in this consent form is provided so that you can decide whether you wish to participate in our study. It is important that you understand that your participation is considered voluntary. This means that even if you agree to participate you are free to withdraw from the experiment at any time, without penalty.

The goal of this study is to collect data on how people collaborate and interact in a team setting when there is a robot team member present. The audio, video and questionnaire data will be analyzed and described in a master thesis. This study is carried out as a part of a master thesis in the Human Media Interaction program at the University of Twente.

During this study you will collaborate with another participant and a robot. Together you will solve a puzzle. Afterwards you will fill out a post-experiment questionnaire and receive a debriefing. The experiment will take about 25 minutes in total. If you have any questions regarding this form or the experiment, feel free to ask them.

Only the researchers in this particular project will have access to the video/audio data. This data will be carefully stored on a secure, external hard drive for at most five years (until January 2022). Non-identifiable data can be made available to other researchers in an anonymized dataset. This experiment poses no known risks to your health. If you have any questions not addressed by this consent form, please do not hesitate to ask.

Contact information

Judith Weda BSc - j.weda@student.utwente.nl
Jered Vroon MSc
Cristina Zaga MSc
Dr. Mariet Theune

Human Media Interaction group
Drienerlolaan 5
7522 NB Enschede
The Netherlands
http://hmi.ewi.utwente.nl/
053-4893740 (Secretary)

Declaration of consent (please tick each checkbox if you consent)

◯ **1.** I agree to participate in this study
◯ **2**. I have read the instructions above and understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.
◯ **3**. I understand that my identifiable data is recorded for research purposes as described above, and can be stored until November 2019.
◯ **4.** I agree for the researcher to use video and audio data of me collected during the experiment in academic articles and presentations (optional).

________________________________ __________________
Name and signature participant Date

________________________________ __________________
Name and signature researcher Date

E Questionnaire Main Study

Robot Behavior

Human Teammate

Please fill in these questions regarding the other participant.

1. **Which team member are you reviewing?**
Mark only one oval.

- The other participant
- The robot

2. **How often does this team member share in planning how the work gets done.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

3. **How often does this team member share in allocating recources according to our team's priorities.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

4. **How often does this team member share in setting our team's goals.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

5. **How often does this team member share in organizing tasks so that work flows more smoothly.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

6. **How often does this team member share in deciding how to go about our team’s work.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

7. **How often does this team member share in providing helpful input about our team's work-related plans.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

8. **How often does this team member share in deciding on the best course of action when a problem arises.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

9. **How often does this team member share in diagnosing problems quickly.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

10. **How often does this team member share in using our team's combined expertise to solve problems.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

11. **How often does this team member share in finding solutions to problems that affect team performance.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

12. **How often does this team member share in identifying problems before they arise**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

13. **How often does this team member share in developing solutions to problems.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

14. **How often does this team member share in solving problems as they arise.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

15. **How often does this team member share in providing support to team members who need help.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

16. **How often does this team member share in showing patience toward other team members.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

17. **How often does this team member share in encouraging other team members when they're upset.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

18. **How often does this team member share in listening to complaints and problems of other team members.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

19. **How often does this team member share in fostering a cohesive team atmosphere.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

20. **How often does this team member share in treating each other with courtesy.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

Robot Teammate

Please fill in these questions regarding the robot.

21. **Which team member are you reviewing?**
Mark only one oval.

- The other participant
- The robot

22. **How often does this team member share in planning how the work gets done.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

23. **How often does this team member share in allocating recources according to our team's priorities.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

24. **How often does this team member share in setting our team's goals.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

25. **How often does this team member share in organizing tasks so that work flows more smoothly.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

26. **How often does this team member share in deciding how to go about our team’s work.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

27. **How often does this team member share in providing helpful input about our team’s work-related plans.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

28. **How often does this team member share in deciding on the best course of action when a problem arises.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	◯	◯	◯	◯	◯	◯	◯	Always

29. **How often does this team member share in diagnosing problems quickly.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	◯	◯	◯	◯	◯	◯	◯	Always

30. **How often does this team member share in using our team's combined expertise to solve problems.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	◯	◯	◯	◯	◯	◯	◯	Always

31. **How often does this team member share in finding solutions to problems that affect team performance.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	◯	◯	◯	◯	◯	◯	◯	Always

32. **How often does this team member share in identifying problems before they arise**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	◯	◯	◯	◯	◯	◯	◯	Always

33. **How often does this team member share in developing solutions to problems.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	◯	◯	◯	◯	◯	◯	◯	Always

34. **How often does this team member share in solving problems as they arise.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	◯	◯	◯	◯	◯	◯	◯	Always

35. **How often does this team member share in providing support to team members who need help.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

36. **How often does this team member share in showing patience toward other team members.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

37. **How often does this team member share in encouraging other team members when they're upset.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

38. **How often does this team member share in listening to complaints and problems of other team members.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

39. **How often does this team member share in fostering a cohesive team atmosphere.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

40. **How often does this team member share in treating each other with courtesy.**
Mark only one oval.

	1	2	3	4	5	6	7	
Never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Always

Robot Behavior

41. **What does the robot do?**

42. **With what attitude is the robot performing its task?**

43. **What do you think the goals of the robot are?**

44. **What do you think the robot wants from you?**

45. **The robot's behavior is enthousiastic.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree								Completely agree

46. **The robot's behavior is uninterested.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree								Completely agree

47. **The robot's behavior is engaged.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

48. **The robot's behavior is distracted.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

49. **The robot's behavior shows effort.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

50. **The robot's behavior shows no effort.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

51. **The robot's behavior is constructive.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

52. **The robot's behavior is destructive.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

53. **The robot's behavior is active.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

54. **The robot's behavior is passive.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

55. **The robot is an essential part of the team.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

56. **The robot is a helpful team member.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Completely agree

57. **Would you like this robot to be in your team?**
Mark only one oval.

- ⬭ Yes
- ⬭ No

58. **Why? / Why not?**

59. **Did the robot make a suggestion? Why do you think so?**

60. **At what line did the robot bring the pieces that were in the field?**
Mark only one oval.

- ⬭ The blue dotted line.
- ⬭ The orange line.

Task

Rate the following regarding the task you just performed.

61. **Mental Demand**
How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very low	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very high

62. **Physical Demand**
How much physical activity was required? Was the task easy or demanding, slack or strenuous?
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very low	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very high

63. **Temporal Demand**
How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very low	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very high

64. **Performance**
How successful were you in performing the task? How satisfied were you with your performance?
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Perfect	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Failure

65. **Effort**
How hard did you have to work (mentally and physically) to accomplish your level of performance?
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very low	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very high

66. **Frustration**
How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very low	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very high

Demographics

67. **What is your age?**

68. **What is your gender?**
Mark only one oval.
- Female
- Male
- Other

69. **What is the highest level of education you finished?**
Mark only one oval.
- High school
- HBO Bachelor
- WO Bachelor
- HBO Master
- WO Master

70. **I have an affinity with robots.**
Mark only one oval.

	1	2	3	4	5	6	7	
Completely disagree								Completely agree

71. **On which side where you seated during the experiment?**
Mark only one oval.
- On the left
- On the right

72. **To what degree do you belief the robot is autonomous?**
Mark only one oval.

	1	2	3	4	5	6	7	
Not autonomous								Fully autonomous

F Principal Component Analysis - Rotated Component Analysis

Rotated Component Matrix[a]

	Components Participants			Components Robot						
	1	2	3	1	2	3	4	5	6	7
How often does this team member share in finding solutions to problems that affect team performance. A	,837			,752						
How often does this team member share in identifying problems before they arise. A	,824			,656			,358			
How often does this team member share in developing solutions to problems. A	,789			,452					,585	
How often does this team member share in providing helpful input about our team's work-related plans. A	,722		,344					,465	,638	
How often does this team member share in diagnosing problems quickly. A	,603		,593	,772						
How often does this team member share in using our team's combined expertise to solve problems. A	,582		,394	,358						,739

How often does this team member share in solving problems as they arise. A	,472	,437	,351	,509	,522						
How often does this team member share in providing support to team members who need help. A		,784			,852						
How often does this team member share in fostering a cohesive team atmosphere. A	,325	,766		,394	,570				-,303		
How often does this team member share in listening to complaints and problems of other team members. A		,692					,810				
How often does this team member share in encouraging other team members when they're upset. A		,681					,763				
How often does this team member share in treating each other with courtesy. A		,679			,418			,616			
How often does this team member share in showing patience toward other team members. A	,384	,628			,391				,614		

How often does this team member share in allocating recources according to our team's priorities. A		,593	,346		,677	,389					
How often does this team member share in organizing tasks so that work flows more smoothly. A			,785					,824			
How often does this team member share in planning how the work gets done. A			,784			,856					
How often does this team member share in deciding on the best course of action when a problem arises. A	,452		,735	,492			,361		,411	-,418	
How often does this team member share in deciding how to go about our team’s work. A	,460		,689	,638				,453			
How often does this team member share in setting our team's goals. A		,498	,657			,837					