

A Longitudinal Experiment About Leadership in a Mixed Human-Robot Team in Comparison to a Human-Only Team

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Abstract. Due to today’s shortage of skilled workers, humanoid robots are already used in workspaces. As technology develops further, this usage is likely to increase even further, making research more important. This paper presents results of a first longitudinal experiment about leadership in mixed human-robot teams compared to human-only teams. Specifically, the integration of a social robot in an office team with a human team leader is assessed. Based on extant leadership theory, we argue that empowering leadership contributes best to the performance of mixed human-robot teams. In this longitudinal experiment, two teams were working in a company and compared for 54 different knowledge work tasks over a project duration of six weeks. One team was a mixed human-robot team while the other was a human-only team. Our results show that both teams can achieve similar performance outcomes. These results give insights into leadership in future workplace with increased use of technology and suggest empowering leadership as a viable option to lead mixed human-robot teams without performance losses.

Keywords: Agent System and Intelligent Speaker, HCI in Society 5.0, Robots, Avatars and Virtual Human, Mixed Human-Robot Team, Robotic Team Assistant, Social Robot, Empowering Leadership, Longitudinal Study.

1 Introduction

“Hey Lena, please summarize our to-do’s from today’s meeting for next week.”
“Alright. I’ll summarize the next steps: Julia talks to the sales team, Marco gets in touch with the customer, and I’ll send around the financing plan.”
“Yes, that’s good, Lena. Please attach them to the protocol.”
“Great, you can find the protocol in the cloud, as always.”

What appears to be a usual team meeting opens a new perspective on our working world: Lena is not a human, but a robotic team assistant in the form of the android robot Elenoide. Processes that are quite familiar to us in today’s office environment such as summarizing a meeting will shape our everyday office life with robots in the future.

Originally, robots were mostly used in the manufacturing sector. For safety reasons, they operated in areas separated from the working human [1]. This situation has fundamentally changed as social robots are being used in various service industries such as retail [2], tourism [3], banking [4], and healthcare [5]. Due to this increasing use, this points to a scenario in the near future, where living with social robots will be as commonplace as living with televisions, cell phones, and computers.

Unlike technologies, social robots have an automated social presence, which is why we treat them as social beings rather than machines [6]. This is enhanced by the fact that social robots are becoming more human-like in terms of emotions, behavior and increasing intelligence [7]. As developments in artificial intelligence and robotics accelerate, social robots will soon meet the challenges of increasingly complex and administrative contexts to support and relieve the team in real time, freeing up resources for other tasks [8].

In 2018, about 82% of executives believed mixed human-robot teams (HRTs) to be commonplace within five years [9]. In a recent survey by Wolf Stock-Homburg [8], participants indicated that they could well imagine working with a robot as a team member (39%) or as a team assistant (50%). As a change in the composition and thus the diversity of teams (e.g., cultural diversity) should always entail an adjustment in leadership behavior [10], the question is whether leadership styles developed for human-only teams can also lead to success for HRTs.

This study focuses on performance implications of leadership, specifically empowering leadership, in HRTs. “Empowering leadership is defined as leader behaviors directed at individuals or entire teams and consisting of delegating authority to employees, promoting their self-directed and autonomous decision making, coaching, sharing information, and asking for input” [11]. Empowering leadership succeeds in the long-term, where the team can get to know each other [12] – following the group development model [13, 14].

Other studies demonstrate that once robots are deployed in existing workspaces such as teams, they inevitably come with consequences such as influencing the (meaning of) work of other employees. This in turn influences how the robots are perceived by the team [15]. However, to our knowledge, this is the first study to investigate the *long-term* impact of empowering leadership in human-robot interactions (HRIs) in the setting of (innovative) teams. Investigating leadership in HRTs is important, since leadership is a means to guide teams to success, as a leader helps reduce uncertainty for new team members, compositions, and in unknown situations. As HRTs bring up many new and perhaps uncertain situations, guidance is particularly relevant and important here. Furthermore, leaders help frame goals and processes in teams. In HRTs, the objectives and especially the processes may be different in the near future due to the integration of artificial intelligence-based technology.

In this study, we compare the performance implications of leadership in HRTs with the performance implications in human-only teams. Specifically, we examine whether empowering leadership can be effectively applied to HRTs with a robot in the role of a team assistant or for human-only teams with a human team assistant. This leads to the research question: Do the performance implications of empowering leadership differ for HRTs and human-only teams?

This study differs from previous research in several important respects: First, to our knowledge, this is the first study that examines leadership in a new type of team, namely HRTs, and its performance implications. Second, this study is conducted in a real corporate setting, whereas the few existing studies on HRTs mostly examine teams outside the corporate setting, e.g., in a laboratory environment. Third, our study examines longitudinal performance implications of empowering leadership in HRTs. This will allow us to make conclusions about stable patterns versus effects of first impression effects that are likely to dominate the results of cross-sectional studies.

2 Study Framework

The conceptual framework (Fig. 1) assumes that empowering leadership in HRTs positively affects team performance over time. The independent variables are the five dimensions of empowering leadership, rooted in empowering leadership theory [16]. Empowering means giving a person or group the power to perform certain activities in a self-determined, autonomous manner [17–21]. Furthermore, it means that parts of the leader’s power are transferred to a person or group [16, 20, 22] rather than being left exclusively in the leader’s position. Therefore, empowering leadership aims to increase the perceived quality of work and to promote greater employee identification with their work goals [23, 24]. An empowering leader, therefore, is “one who leads others to lead themselves” [25].

Empowering leadership includes five dimensions [16], namely leading by example (setting high standards by working hard oneself), participative decision-making (encouraging and considering ideas and suggestions), coaching (guiding independent problem solving), informing (explaining expectations and decisions), and showing concern (caring for the team). In our study, empowering leadership is captured as initial leader activity at time t_1 (see Fig. 1).

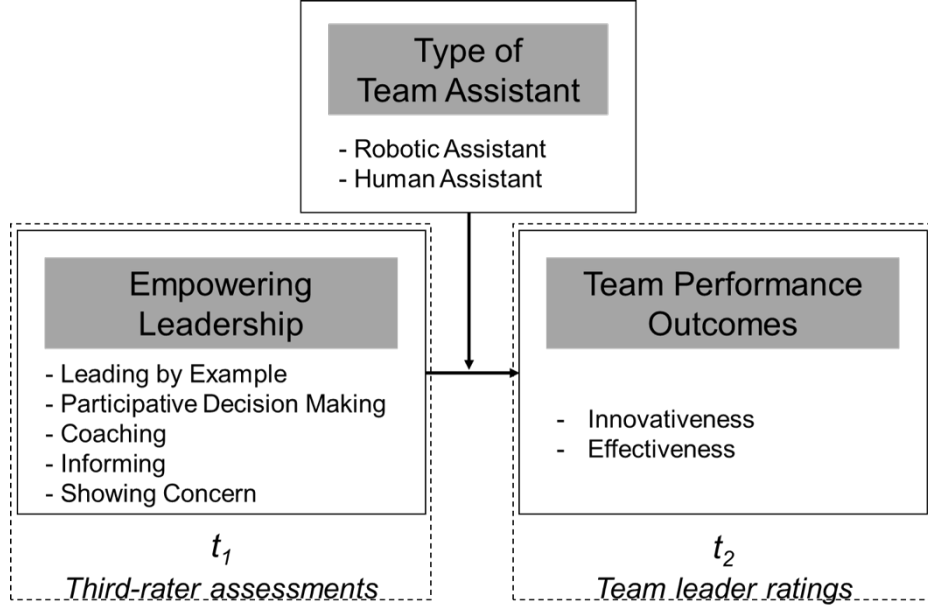


Fig. 1. Study Framework of the Influence of the Five Dimensions of Empowering Leadership on Team Performance in Human and Robotic Team Assistant Settings

The implications of empowering leadership are proposed to affect important team performance outcomes such as team innovativeness and team effectiveness as dependent variables [26, 27]. Team innovativeness is defined as “the flexibility and willingness to accept new ways to create knowledge-based solution” [28]. In contrast, effectiveness is about the quantitative and qualitative output of a team and the effect (e.g., satisfaction) the team has on its members [29]. The performance outcomes are examined on the long run, i.e., these variables are measured after the empowering leadership has been practiced in the team.

Finally, we examine the type of team assistant as moderator. A moderating variable strengthens or weakens the strength of a relationship under consideration [30]. Specifically, we examine whether the performance implications of empowering leadership are stronger for HRTs or human-only teams. The perception and acceptability of HRI with service robots is affected by robots’ anthropomorphic (i.e., human-like [31]) design [32] as well as an appropriate human-oriented application and placement of these service robots [33, 34]. An android robot is “an artificial system designed with the ultimate goal of being indistinguishable from humans in its external appearance and behavior” [35]. This is the best example of a social robot due to its anthropomorphic design [36] to resemble a human. Therefore, we used an android robot as the robotic team assistant.

3 Empirical Study

The setting of this real-world experiment was placed in the work environment of a small consulting firm. To ensure a realistic setting and conditions for teamwork, the setting was included into the workspace of the company. The setting included a meeting table as well as digital and analog whiteboards (see Fig. 2). To minimize outside influences on the experiments, participants were not allowed to bring any personal devices and all necessary technologies including classical office software were provided by the company. Microphones and cameras were placed in the environment, not interfering with the interaction. Participants were hired as normal (junior) consultants and had solely been informed that these measurements were used to better understand a team’s functioning while working on a consulting project.

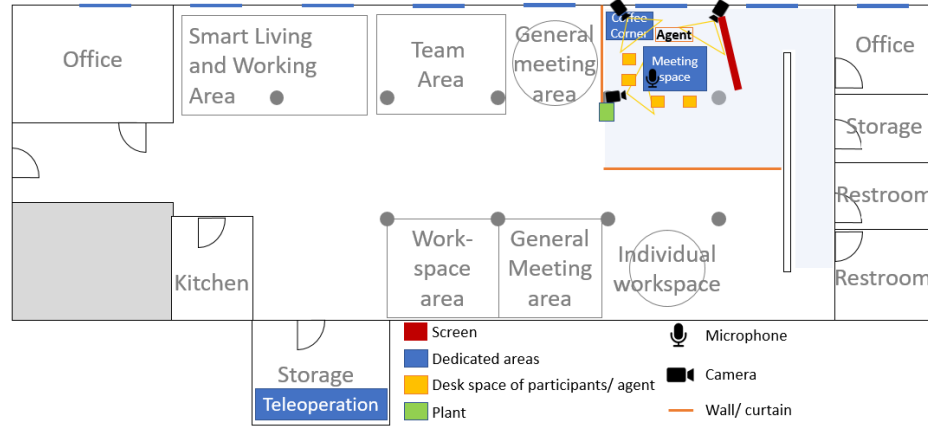


Fig. 2. Experimental Setup

For the integration of the team assistant in the HRT, the android robot “Elenoide” was used (see Fig. 3. , right). This robot is 1.70m tall, has a total of 49 degrees of freedom and the exoskeleton is covered with a skin-like layer. The aim is to give a human-like appearance. Elenoide was placed at the meeting table like the other team members and teleoperated by the Wizard of Oz method [37], to be able to reach the closest real representation not only in the physical presence, but also in the team behavior (see Fig. 3, left).

The scope of tasks of the team assistance (human or robotic) included the following tasks over the course of the experiment: Providing information (e.g., data management, simple research, time management), performing tasks (e.g. protocols, mails, presentations, tracking milestones), and improving materials (e.g. correcting content on request, asking questions of understanding in the case of unclear/nonsensical work assignments, suggesting improvements.)



Fig. 3. Mixed Human-Robot Team (left) & Android Robot Elenoide (right) (Photos: ©leap in time)

3.1 Sample and Measurement

To recruit participants, we distributed job postings for (junior) consultants in the form of advertising materials for a project called “Innovation Bootcamp” on social media and job portals. The 67 respondents were confidentially screened for individual qualifications and availability and proximity to the company was used as the first exclusion criterion to minimize external complications. Three members per team (Human-only team: Age: 20, 21, 23, Male: 100%; HRT: Age: 21, 29, 66, Male: 100%) were selected who met the requirement profiles of the expert roles. For the human-only team, the team assistant was fulfilled by a confederate, fully adapting to the range of tasks of the robotic assistant.

The participants signed the privacy statement and informed consent form as part of their work contracts. In a following pretest, the Big Five personality traits [38], robot anxiety [39], technology affinity [40], and robot experience were examined and used as extended exclusion criteria. No extreme values occurred in these tests. Based on the results, the participants were distributed between the human-only team and the HRT.

Data were collected regularly during the experimental phase. To keep the queries minimal for the participants, questionnaires on team performance were completed by third raters and the team leader. The third raters have been independent raters who focused on the independent variable (see Fig. 1) and observed and evaluated the leader to ensure that the performed empowering leadership style was constant. Table 7 and Table 8 show the dimensions according to which the third raters evaluated which parts of empowering leadership or directive leadership were performed.

The data collected by the team leader explicitly includes the two performance data under examination, team innovativeness and team effectiveness, which are used for as the dependent variables of the study framework (see Fig. 1). These two were each collected hourly after every task and consist of the aspects in Table 1.

Table 1. Team Performance Data – Dependent Variables

<i>(a) Team Innovation – Within the last hour, the team was very much engaged in ...</i>
- ... find new solutions to problems.
- ... develop new ideas for difficult questions.
- ... seek new working methods, techniques or tools.
- ... transform innovative ideas into useful applications.
- ... evaluating the usefulness of innovative ideas.
<i>(b) Team Effectiveness – Within the last hour ...</i>
- ... the team mostly achieved the team goals.
- ... the team performed very well.
- ... the team was very successful.
Note: Response range: totally disagree – totally agree (7-point Likert scale); Measurement: hourly; Rater: team leader

Thus, two types of feedback were collected from the team members directly. First, in the daily standup which assessed the motivation and willingness to work of all team members (5-point Likert scale). Second, after every hour at the end of each sprint, an individual assessment of the complexity and satisfaction of the distribution of competencies in the team (5-point Likert scale). The purpose of these surveys, each was communicated as best practices of the company. In a post-survey questionnaire, changes in perceptions were investigated. The actual intent of the experiment was revealed to the participants afterwards in a debriefing conversation.

3.2 Experimental Procedure

The six selected participants were divided into two teams with the task of developing a market entry strategy for a chemical company to extent their business. This included the analysis of markets and stakeholders, the elaboration of new products and services, and the development of a stepwise market-entry plan. In both teams, the three participants had expert roles in the areas of market strategy, finance, and technology development. Furthermore, the role of the team assistant was taken by a fourth team member – either an android robot or a human (see Fig. 3.). This measurement was taken in order to increase the comparability between the performance outcomes of the two teams, as both had similar background knowledge. Finally, each team was complemented by the same human team leader who performed the empowering leadership as a confederate.

Over the project duration of six weeks, the agile working teams had to work on three project days per week. Organized into sprints [41], each team had the same 54 tasks to complete. A project day began with a ten-minute daily standup initiated by the team leader with the purpose of motivating the team, recalling past steps, and providing an outlook on the day's upcoming challenges. Between each of the following three one-hour sprints, there was a break of about 15 minutes, giving the team the opportunity to relax and socialize; this applied equally to conversations with the robot as well as the confederate, which were, however, kept to a minimum and small talk. The project day ended with a daily scrum after the third sprint. Here, individual feedbacks were brought

together, discussed in the team, and supplemented by the team leader with further recommendations for action.

3.3 Manipulation of Empowering Leadership as Independent Variable

The manipulation of “empowering leadership” was conducted in several steps. In a first step, we conducted a literature review on the most common conceptualizations and operationalizations of empowering leadership. Following the well-known measurement approach of Arnold et al. [16], we identified important aspects for the five dimensions of empowering leadership (see Fig. 1). In the second step, we derived the specific leadership behaviors, the leader should exhibit during the experimental study. In step three, the leader was trained on empowering leadership by a professional leadership trainer. The important aspects for the five dimensions of empowering leadership as proposed by Arnold et al. [16], and specific behaviors for the team leaders are listed in Table 7.

Empowering leadership was measured once the daily measured team performance remained constant over three measurements, which was reached after 1.5 weeks (denoted t_1 , Fig. 1). As Table 2 shows, empowering leadership was highly rated for both teams and there were no significant differences between the teams in terms of empowering leadership. Therefore, the manipulation can be considered successful.

Table 2. Manipulation Check – t-Test results for Empowering Leadership

Independent Variables	HRT M(SD)	Human-only Team M(SD)	Δ Mean	p-Value
Leading by Example	6.90 (.11)	6.20 (.88)	.70	.08
Coaching	6.73 (.20)	6.50 (.35)	.23	.20
Participative Decision Making	5.58 (.27)	5.67 (.00)	-.09	.47
Informing	4.75 (.46)	3.83 (1.28)	.92	.13
Showing Concern	6.75 (.16)	6.80 (.22)	-.05	.66
Notes: M = Mean Value; Δ M = Mean Difference; SD = Standard Deviation; * $p < .05$, ** $p < .01$; t-test				

4 Preliminary Results

We proposed a study framework for a real-world experiment to compare the effects of empowering leadership on the performance variables over time in a consulting company setting. Drawing on the extant leadership literature, we tested how empowering leadership affected the team innovativeness and team effectiveness. In addition, we took the type of team assistant as a moderating effect into account and examined, whether HRT or human-only team responded differently. The results in Table 3 and Table 4 show that team performance in the HRT and the human-only team did not differ significantly in either team innovativeness or team effectiveness at time points t_1 and t_2 . Similarly, when comparing the development between t_1 and t_2 for HRT (see Table 5) and human-only team (see Table 6), no significant differences can be found between the two groups. At the end of the experiment (at t_2), on average, both teams were able

to score values above five (on a 7-point Likert scale). The difference in means (Δ Mean) for the two teams was rather low for both teams (1% of the scale for team innovation and 1.6% for team efficiency).

Table 3. Preliminary Results of the Study – Team Performance for t_1

Dependent Variables	HRT M(SD)	Human-only Team M(SD)	Δ Mean	p-Value
Team Innovativeness	4.67 (.81)	5.00 (.40)	-.33	.56
Team Effectiveness	5.11 (1.02)	5.44 (.51)	-.33	.64
Notes: M = Mean Value; Δ M = Mean Difference; SD = Standard Deviation; * $p < .05$, ** $p < .01$; t-test				

Table 4. Preliminary Results of the Study – Team Performance for t_2

Dependent Variables	HRT M(SD)	Human-only Team M(SD)	Δ Mean	p-Value
Team Innovativeness	5.20 (.35)	5.27 (.76)	-.07	.90
Team Effectiveness	5.67 (.33)	5.56 (.38)	.11	.73
Notes: M = Mean Value; Δ M = Mean Difference; SD = Standard Deviation; * $p < .05$, ** $p < .01$; t-test				

Table 5. Preliminary Results of the Study – Development of Team Performance for the HRT between t_1 and t_2

Dependent Variables	HRT M(SD)	Human-only Team M(SD)	Δ Mean	p-Value
Team Innovativeness	4.67 (.81)	5.20 (.35)	-.53	.35
Team Effectiveness	5.11 (1.02)	5.67 (.33)	-.56	.42
Notes: M = Mean Value; Δ M = Mean Difference; SD = Standard Deviation; * $p < .05$, ** $p < .01$; t-test				

Table 6. Preliminary Results of the Study – Development of Team Performance for the Human-only team between t_1 and t_2

Dependent Variables	HRT M(SD)	Human-only Team M(SD)	Δ Mean	p-Value
Team Innovativeness	5.00 (.40)	5.27 (.76)	-.27	.62
Team Effectiveness	5.44 (.51)	5.56 (.38)	-.11	.78
Notes: M = Mean Value; Δ M = Mean Difference; SD = Standard Deviation; * $p < .05$, ** $p < .01$; t-test				

5 Conclusion

The departure point of this study were today's shortage of skilled workers and the observation that social robots increasingly enter our daily life; with only few studies that examine social robots in teams. These studies were conducted in laboratory settings and

followed a one-time (first) interaction between humans and robots. To our knowledge this is the first of type study that investigates HRT in with robotic team member on a long-term basis. Team research indicates that newly constituted teams are associated with high uncertainties and the need for strategic guidance. This uncertainty may be even higher for teams in HRTs. We therefore attempt to shed light on the roles of leadership, i.e., empowering leadership for the innovation and the effectiveness of such teams in an office environment.

Relying on empowering leadership theory [16], we examined the performance implications of empowering leadership in a HRT compared to a human-only team. Our independent variable was empowering leadership over time, while team innovation and effectiveness represented our dependent variables. The results show that empowering leadership has similar performance implications for HRTs and human-only teams. This indicates that empowering leadership is a fruitful passway for HRT, as well, and should inspire to explore the application of existing leadership theory in HRTs.

5.1 Limitations and Areas for Future Research

In this study, empowering leadership was evaluated through an elaborate real-life design. For future studies should examine more teams to obtain a larger sample. This study only provides first ideas but no generalizations can be made from two teams. In addition, empowering leadership was manipulated to be always high. Further studies should compare these results at a low manipulation level or even different leadership styles.

As research on leadership in mixed human-robot teams is scarce, our study contributes to extant research by examining the long-term effects of empowering leadership on the team innovativeness and team effectiveness. This offers valuable insights into recommendations for action for team leaders to increase the viability of bureau robots in modern working environments.

6 Appendix

Table 7. Manipulation of Team Leadership – Empowering Leadership

Important Aspects [16]	Concrete Empowering Leadership Behaviors During the Longitudinal Study
(a) Leading by Example	
Sets high standards for performance by his/her own behaviour	<ul style="list-style-type: none"> • Shows confident appearance • Gives constructive feedback on solutions
Works as hard as he/she can	<ul style="list-style-type: none"> • Shows commitment • Ready for questions at any time
Works as hard as anyone in my work group	<ul style="list-style-type: none"> • Handles own work packages • Represents an employee of the consulting company
Sets a good example by the way he/she behaves	<ul style="list-style-type: none"> • Friendly, supportive • Communicative, open
Leads by example	<ul style="list-style-type: none"> • Punctuality • Involves all team members
(b) Participative Decision Making	
Encourages work group members to express ideas/suggestions	<ul style="list-style-type: none"> • Addresses individual team members directly • Asks open questions
Listens to my work group's ideas and suggestions	<ul style="list-style-type: none"> • Is attentive • Responds to the statements
Uses my work group's suggestions to make decisions that affect us	<ul style="list-style-type: none"> • Responds to the suggestions of the team • Empowers the team to find solutions
Gives all work group members a chance to voice their opinions	<ul style="list-style-type: none"> • Asks questions about the emotional state • Asks for the opinions of all team members
Considers my work group's ideas when he/she disagrees with them	<ul style="list-style-type: none"> • Remains objective / fact-based • Tries to find compromises / middle ground if necessary
Makes decisions that are based only on his/her own ideas	<ul style="list-style-type: none"> • Specifies how to proceed regardless of team suggestions • Aligns the team to a vision
(c) Coaching	
Helps my work group see areas in which we need more training	<ul style="list-style-type: none"> • Points out potential for development • Challenges the group in relevant areas
Suggests ways to improve my work group's performance	<ul style="list-style-type: none"> • Names alternative idea development methods • Gives tips on how the team can work better together
Encourages work group members to solve problems together	<ul style="list-style-type: none"> • Refers to connecting elements / synergy • Addresses positive team experiences
Encourages work group members to exchange information with one another	<ul style="list-style-type: none"> • Refers to potential contacts and connection points in the team

Provides help to work group members	<ul style="list-style-type: none"> • Resolves (task) uncertainties • Is available as a (conflict) mediator
Teaches work group members how to solve problems on their own	<ul style="list-style-type: none"> • Teaches to analyse a task • Teaches to divide a task in a team
Pays attention to my work group's efforts	<ul style="list-style-type: none"> • Responds to ideas/suggestions • Builds on previous results
Tells my work group when we perform well	<ul style="list-style-type: none"> • Praises good cooperation • Praises good results
Supports my work group's efforts	<ul style="list-style-type: none"> • Points out good directions • Gives a sense of tailwind/coverage
Helps my work group focus on our goals	<ul style="list-style-type: none"> • Reminds of client's objectives • Reminds of structuring of processing
Helps develop good relations among work group members	<ul style="list-style-type: none"> • Points out common ground • Strengthens team spirit through compliments
(d) Informing	
Explains company decisions	<ul style="list-style-type: none"> • Explains the nature of the project • Explains changes in the project
Explains company goals	<ul style="list-style-type: none"> • Differentiates between client and consulting firm • Explains the vision of the project
Explains how my work group fits into the company	<ul style="list-style-type: none"> • Explains the added value of the team • Praises well-founded work
Explains the purpose of the company's policies to my work group	<ul style="list-style-type: none"> • Refers to high-quality collaborations (internal/external) • Trusts team competence
Explains rules and expectations to my work group	<ul style="list-style-type: none"> • States rules of conduct • Provides freedom in processing
Explains his/her decisions and actions to my work group	<ul style="list-style-type: none"> • Maintains fairness between groups • Trusts team decisions
(e) Showing Concern / Interacting with the Team	
Cares about work group members' personal problems	<ul style="list-style-type: none"> • Offers individual feedback • Considers unfavourable circumstances
Shows concern for work group members' well-being	<ul style="list-style-type: none"> • Cares about the emotional state • Provides a failure-tolerant environment
Treats work group members as equals	<ul style="list-style-type: none"> • Treats everyone equally • Takes the time to listen to everyone
Takes the time to discuss work group members' concerns patiently	<ul style="list-style-type: none"> • Is always available to address concerns • Does not spread a hectic mood • Talks about satisfaction
Shows concern for work group members' success	<ul style="list-style-type: none"> • Inquires about progress regularly • Shows enthusiasm for progress
Stays in touch with my work group	<ul style="list-style-type: none"> • Regularly checks in with the group • Does not distance himself from the team
Gets along with my work group members	<ul style="list-style-type: none"> • Conducts conversations at eye level • Has a good relationship with everyone

Gives work group members honest and fair answers	<ul style="list-style-type: none"> • Feedback is always constructive • Feedback takes team dynamics into account
Knows what work is being done in my work group	<ul style="list-style-type: none"> • Keeps up to date on steps and successes • Knows who has what share in the team
Finds time to chat with work group members	<ul style="list-style-type: none"> • Talks about emotional state • Talks about difficulty
Note: Response range: totally disagree – totally agree (7-point Likert scale); Measurement: daily; Rater: third rater	

Table 8. Delimitation of Team Leadership – Directive Leadership [42]

Important Aspects	Concrete Directive Leadership Behaviors During the Longitudinal Study
Expects his/her employees to follow my instructions precisely.	<ul style="list-style-type: none"> • Requests to take certain steps • Does not tolerate differences
Motivates employees by letting them know what will happen to them if their work is unsatisfactory.	<ul style="list-style-type: none"> • Assigns responsibility (blame) • Communicates intolerance for mistakes
Requires employees to submit detailed reports of their activities.	<ul style="list-style-type: none"> • Requires detailed reporting from each role • Monitors the execution of roles
Makes most decisions for employees.	<ul style="list-style-type: none"> • Defines its solution vision • Does not allow for free action
Supervises employees very closely.	<ul style="list-style-type: none"> • Monitors communication • Intervenes in team dynamics
Supervisor have to lay out goals and guidelines, otherwise subordinates will be passive and get nothing accomplished.	<ul style="list-style-type: none"> • Assigns tasks • Specifies how and where exchange takes place
Expects to carry out instructions immediately.	<ul style="list-style-type: none"> • Expects direct understanding of task • Expects immediate action
Note: Response range: totally disagree – totally agree (7-point Likert scale); Measurement: daily; Rater: third rater	

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