No man is an island: Will service robots reduce employee loneliness?

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Citation:
Liu, X., **Lin, Z.,** Fang, S., & Zhang, L. (2025). No man is an island: Will service robots reduce employee loneliness?. *Tourism Management, 109*, 105151. https://doi.org/10.1016/j.tourman.2025.105151

Abstract

Although the application of robotics technology in tourism and hospitality service scenarios has been widely explored, few studies have investigated the impact of service robots on employee workplace loneliness. To address this issue, we conducted two studies: Study 1, consisting of a scenario-based online experiment (Study 1a) and a field experiment (Study 1b); Study 2, a two-wave survey. The results reveal that the social presence of robots reduces workplace loneliness, with employee-robot rapport and interpersonal closeness serving as partial mediators. The need for human interaction moderates the relationships between robot social presence and employee-robot rapport and interpersonal closeness, as well as the mediating effects. This study clarifies the mechanisms and boundary conditions of the impact of service robots on employee loneliness by extending social presence theory, contributing to the literature on service robots, and also provides insights for robotics management and human resource management in the tourism and hospitality sector.

Keywords: Service robot; Social presence; Workplace loneliness; Employee-robot rapport; Interpersonal closeness; Need for human interaction.

1. Introduction

The advancements in artificial intelligence have led to an increased presence of service robots in tourism and hospitality settings (de Kervenoael et al., 2020; Hoang & Tran, 2022; Liu et al., 2022; Ma et al., 2022; Xu et al., 2023). These robots are increasingly deployed in hotels, airports, restaurants, and other venues to enhance service delivery (Belanche et al., 2020; Tussyadiah, 2020). Recent industry reports show that the global hospitality robot market is experiencing rapid growth, with projections estimating it will reach $2,159.77 million by 2030, driven by a compound annual growth rate (CAGR) of 25.19% (Cognitive Market Research, 2024). This technological integration has fundamentally transformed how services are provided and how employees perform their roles (Belanche et al., 2020).

Studies have highlighted both the benefits and challenges of service robots (de Kervenoael et al., 2020; Pitardi et al., 2024; Ma et al., 2022; Xu et al., 2023). On the positive side, service robots can take over routine and mundane tasks, such as handling luggage at hotels, providing directions at airports, conducting guided tours at museums, and facilitating basic interactions with visitors at tourist attractions (Huang & Rust, 2018). They have been shown to enhance productivity and employee satisfaction (Lacity & Willcocks, 2016) while augmenting employees' cognitive capacity for more meaningful interactions (Barrett et al., 2012). However, significant challenges remain, including employee frustration, perceived loss of autonomy (Barrett et al., 2012), difficulties in task coordination (Beane & Orlikowski, 2015), and tensions arising from role changes in service delivery (Green et al., 2008).

While existing research has extensively examined the operational impacts of robots, a critical gap remains in understanding their influence on employee well-being, particularly workplace loneliness. Addressing this gap is imperative, as workplace loneliness represents a growing challenge within the industry. Recent reports have highlighted the severity of workplace loneliness. The Gallup report (2024) reveals that 20% of global employees experience workplace loneliness, with the prevalence notably higher among those under 35. Similarly, the 2024 *Work in America* survey (APA, 2024) presents even more alarming figures, reporting that 45% of workers experience workplace loneliness. This issue is particularly pronounced in the hospitality sector, where irregular working hours, low social status, and high-pressure environments often foster social isolation (Boukis et al., 2023; Liu et al., 2021). *Spa Executive Magazine* (2024) has aptly termed this phenomenon a "loneliness epidemic."

Workplace loneliness is an unpleasant experience arising from perceived deficiencies in the quantity or quality of social relationships at work (Lam & Lau, 2012; Wright et al., 2006). When employees experience loneliness at work, their self-esteem and self-efficacy are negatively impacted (Erdil & Ertosun, 2011), leading to reduced job satisfaction, lower organizational commitment, and increased turnover intentions (Ayazlar & Güzel, 2014; Ozcelik & Barsade, 2018). These effects are especially pronounced in hospitality settings, where the combination of irregular working hours, low social status, and fast-paced work environments creates conditions conducive to social isolation (Boukis et al., 2023; Liu et al., 2021).

Social presence theory (Short et al., 1976; Biocca et al., 2003) provides a valuable theoretical lens for understanding how service robots might address workplace loneliness. This theory explains how individuals perceive and respond to others, including technological entities, as social actors in mediated environments. It suggests that when technology exhibits social presence – the degree to which it is perceived as a sentient social entity – it can facilitate meaningful social interactions and relationship formation. While studies have shown promise in using robots to alleviate loneliness among older adults (Berridge et al., 2023) and hospitalized children (Moerman et al., 2019), their potential for addressing workplace loneliness remains unexplored.

This leads to our central research questions: How does the social presence of service robots affect employee workplace loneliness in the hospitality industry? Through what mechanisms does this effect occur? And how do individual differences influence these relationships? Drawing upon social presence theory, we propose two potential pathways through which robots' social presence might reduce workplace loneliness: first, by fostering employee-robot rapport, reflecting the theory's emphasis on relationship formation; and second, by enhancing interpersonal closeness among colleagues and with customers, building on the theory's insights about technology-mediated social connections. We further examine how individual differences in need for human interaction moderate these relationships, as social presence theory suggests that personal preferences influence technology-mediated social experiences.

To test our hypotheses, we conducted two studies in the tourism and hospitality sector. Study 1 consists of a scenario-based online experiment (Study 1a) and a natural field experiment (Study 1b) to establish the main effect of robot social presence on workplace loneliness and examine the mediating roles of employee-robot rapport and interpersonal closeness. Study 2 employs a two-wave survey to validate the findings of Study 1 and further investigate the moderating role of the need for human interaction and the moderated mediation effects.

This research makes several significant contributions. First, it introduces a novel approach to addressing workplace loneliness in hospitality by examining service robots as social actors rather than mere operational tools. Second, it extends social presence theory to employee-robot interactions in hospitality workplaces, providing new insights into how advanced technologies can reshape workplace social dynamics. Third, it addresses the critical gap in hospitality technology research by focusing on employee well-being rather than customer experience, offering practical strategies for enhancing workplace conditions and potentially reducing turnover in an industry struggling with retention.

2. Literature review and hypotheses development

2.1. The impacts of service robots on employees in tourism and hospitality

Service robots have become a significant focus of academic research (Borghi & Mariani, 2024), particularly regarding their adoption impacts beyond mere acceptance (Kong et al., 2023). While research has extensively covered customer impacts (Borghi & Mariani, 2024; Holthöwer & Van Doorn, 2023; Lei, Shen, & Ye, 2021), studies on employee implications remain limited (Kong et al., 2023; Leung et al., 2023; Li et al., 2024). This gap is noteworthy as employees are key executors of service in robotic hotels, directly affecting service quality and customer experience (Song et al., 2022).

Our literature review (see Table 1 for a summary) reveals that existing research primarily focuses on employee work performance metrics, including turnover intention (Koo et al., 2021; Li et al., 2019; Parvez et al., 2022; Shum et al., 2024; Yu et al., 2022; Zhang & Jin, 2023), work competence and productivity (Kong et al., 2021; Song et al., 2022; Ding, 2021; Guan et al., 2024; Qiu et al., 2022; Liang et al., 2022; Tan et al., 2024; Li et al., 2024), and career identity (Wang et al., 2024). However, employees' psychological well-being, though essential for overall workplace health, remains understudied (Phillips et al., 2023).

Studies have examined AI and robot-related awareness (Li et al., 2019; Liang et al., 2022; Kong et al., 2021; Parvez et al., 2022; Tan et al., 2024; Zhang & Jin, 2023), perceived risk (Song et al., 2022), and insecurity (Koo et al., 2021). While service robots' social presence significantly impacts human-robot interactions (Flavián et al., 2024; Singh et al., 2021; Yoganathan et al., 2021), its effect on employees remains largely unexplored. The impact of service robots can be both positive and negative, varying based on robot characteristics, employee factors, and outcomes. For example, while AI awareness may increase job insecurity and mobility (Zhang & Jin, 2023), positive perceptions of work autonomy in robot interactions can promote innovative behavior and reduce insomnia (Li et al., 2024). Our research therefore investigates how service robots' social presence affects employee workplace loneliness, an important aspect of employee well-being.

2.2. Social presence of robots and workplace loneliness

Social presence, introduced by Short and colleagues in 1976, refers to how much an individual perceives another entity as being present and engaged in a social interaction. According to social presence theory, different communication media have varying capacities to convey social cues and create a sense of "being with others." High social presence contributes to effective communication, increased intimacy, and better interpersonal involvement (Short et al., 1976; Biocca et al., 2003). The theory has evolved to explain and predict user behavior across various technology-mediated environments, from traditional computer-mediated communication to newer virtual and augmented reality platforms (Mallmann & Maçada, 2021; Cui et al., 2021; Oh et al., 2018; Richardson et al., 2017; Shin, 2018).

In human-robot interactions, social presence manifests as the perception of robots as social actors capable of eliciting emotional and behavioral responses (Kim et al., 2022; van Doorn et al., 2017). Research demonstrates that high social presence in robots enhances customer rapport and trust (Kim et al., 2022), influences service outcomes through perceptions of warmth and competence (van Doorn et al., 2017), and increases technology acceptance through human-like qualities (Fernandes & Oliveira, 2021). While these findings primarily focus on customer interactions, they highlight how social presence can foster meaningful connections in human-robot environments.

Consistent with social presence theory, when people interact with technology that feels social and human-like, they can form real connections and feel less isolated (Biocca et al., 2003). Service robots with a high social presence, characterized by human-like qualities and interactive capabilities, can act as "technological companions," offering emotional support, companionship, and assistance to employees (Odekerken-Schröder et al., 2022; Wirtz et al., 2018; Jones et al., 2021). They foster a sense of connection by simulating social interactions that fulfill employees' relational needs, thereby alleviating feelings of isolation (Yang & Gao, 2023). Moreover, the perception of social presence helps create a sense of "being with others," which is particularly valuable in environments that lack traditional human interactions (Biocca et al., 2003; Short et al., 1976). Based on these arguments, we propose the following hypothesis:

Hypothesis 1: The social presence of robots reduces employee workplace loneliness.

2.3. The mediating role of employee-robot rapport

Rapport is generally defined as a personal connection between two interactants (Gremler & Gwinner, 2000). In the context of human-robot interactions, employee-robot rapport refers to the positive bond human employees establish with their robot colleagues (Qiu et al., 2020). This concept has gained significance as a growing number of studies suggest that robots can become valued work partners for employees and even be seen as workplace friends (Archer, 2021; Paluch et al., 2022).

Social presence theory suggests that robots' social presence would facilitate a closer relationship between them and the actors (Kim et al., 2022). We therefore propose that the social presence of robots can foster employee-robot rapport, particularly in the tourism and hospitality industry where service interactions are frequent and crucial. Robots with higher social presence are more likely to be perceived as engaging and responsive interaction partners (Kim et al., 2022; van Doorn et al., 2017). When robots exhibit social behaviors and cues, such as engaging in small talk, expressing empathy, or using humor, they are more likely to establish rapport with human employees (Fernandes & Oliveira, 2021).

Furthermore, we argue that employee-robot rapport can reduce workplace loneliness, a significant concern in the tourism and hospitality industry (Jung & Yoon, 2022; Kuriakose et al., 2023). When employees experience a positive social bond with a service robot, they may feel less isolated and more supported in their work environment (Odekerken-Schröder et al., 2020; Wirtz et al., 2018). This is particularly important given the industry factors that contribute to social isolation, such as irregular working hours and fast-paced work environments (Boukis et al., 2023; Liu et al., 2021).

Several studies have explored how robotic attributes influence the quality of human-robot relationships and further impact human experiences (e.g., Kim et al., 2022; Qiu et al., 2020). These findings suggest that the emotional attachment employees develop with robots, viewing them as entities with which high-quality relationships can be fostered, may potentially alleviate feelings of loneliness. This perspective aligns with the idea of robots as "technological companions" (Jones et al., 2021), which may be especially beneficial in an industry known for its challenges in maintaining consistent human-to-human interactions due to shift work and high turnover rates. Based on these arguments, we propose the following hypotheses:

Hypothesis 2a: The social presence of robots positively affects levels of employee-robot rapport.

Hypothesis 2b: Employee-robot rapport negatively affects workplace loneliness.

Hypothesis 2c: Employee-robot rapport mediates the relationship between the social presence of robots and workplace loneliness.

2.4. The mediating role of interpersonal closeness

Interpersonal closeness refers to the perceived psychological proximity between two people, characterized by feelings of connectedness (Dubois et al., 2016). Drawing from social presence theory, service robots with high social presence can enhance social interactions and foster a more engaging and collaborative work environment, thereby promoting interpersonal closeness (Christou et al., 2020). Specifically, the human-like qualities of service robots create a warmer, more harmonious work atmosphere, where employees view robots as valued colleagues and share positive experiences working alongside this advanced technology (Liu & Xie, 2024), which helps to develop closer relationships with one another (Liang et al., 2022). Furthermore, when robots effectively augment service delivery, they provide employees with more opportunities for meaningful interactions (van Doorn et al., 2017; Kim et al., 2022). The presence of robots enables employees to better serve customers, facilitating deeper communication between customers and employees (Qiu et al., 2020). As a result, robots with high social presence allow employees to focus on building meaningful connections (Prentice et al., 2020). Therefore, we propose:

Close interpersonal relationships at work provide social support and a sense of belonging, and help create a sense of community and integration, which are essential for reducing feelings of isolation (Fan et al., 2023). When employees feel supported by their colleagues, they are better able to navigate workplace challenges and stress, which significantly reduces feelings of loneliness (Ozcelik & Barsade, 2018). In addition, interpersonal closeness fosters a positive cycle of interaction: as employees develop closer relationships, they tend to feel more approachable and open to interactions with others, which further counters the emotional effects of loneliness (Ozcelik & Barsade, 2018; Fan et al., 2023). Therefore, we propose:

Hypothesis 3a: The social presence of robots positively affects levels of interpersonal closeness between humans.

Hypothesis 3b: Interpersonal closeness negatively affects workplace loneliness.

Hypothesis 3c: Interpersonal closeness mediates the relationship between the social presence of robots and workplace loneliness.

2.5. The moderating role of the need for human interaction

The need for human interaction (NFHI) is an individual difference variable that reflects a person's desire for interpersonal contact in service encounters (Dabholkar &

Bagozzi, 2002). Originally proposed by Dabholkar (1999), NFHI is defined as the degree of an individual's need for interpersonal interaction with service employees. Research has identified distinct characteristics associated with different levels of NFHI. Individuals with high NFHI prefer to interact with service employees and tend to avoid technological encounters. They may be less comfortable with technology-mediated services (Dabholkar & Bagozzi, 2002; Hu et al., 2021; Kelly et al., 2019). Conversely, individuals with low NFHI tend to seek self-directed services and are more open to using self-service technologies and interacting with machines (Fernandes & Oliveira, 2021; Wirtz et al., 2018).

The tourism and hospitality industry traditionally emphasizes human interaction, however, the increasing adoption of AI and robotics is reshaping service delivery (Min et al., 2015; Park & Kim, 2019). This technological shift potentially affects employee roles, job satisfaction, and customer experiences in ways that may vary based on individual NFHI levels. As a personal trait, NFHI may moderate the effect of employee relationships with robots, fellow colleagues, and customers. Existing research has explored the boundary effects of NFHI on individual attitudes, feelings, and behaviors in the context of customer-robot interactions. Hu et al. (2021) found that NFHI can moderate the remedial effects of human-robot interaction failures. Moreover, Lv et al. (2024) argued that in collaborative human-robot work scenarios, positive customer interactions can mitigate the negative impact of employee social interaction overload.

Accordingly, we propose that NFHI moderates the relationships between the social presence of robots, employee-robot rapport, and interpersonal closeness in the tourism and hospitality industry. Studies on social presence theory suggest that the strength of relationships is likely to be enhanced for individuals who are willing to communicate with service robots (e.g., Kim et al., 2022). For employees with low NFHI, there is a reduced desire to interact with humans, and the social presence of robots may be particularly effective in fostering employee-robot rapport. These individuals are more likely to be comfortable interacting with robots and may be more receptive to the social cues and behaviors exhibited by socially present robots (Fernandes & Oliveira, 2021; Kim et al., 2022). When employees have low NFHI, the social presence of robots will encourage greater harmony between human employees and robots. However, because these individuals are less inclined to establish emotional relationships with their colleagues or customers, the effect of the social presence of robots on interpersonal relationship closeness will be weaker. Based on these arguments, we propose the following hypotheses:

Hypothesis 4a: NFHI negatively moderates the relationship between the social presence of robots and employee-robot rapport in the tourism and hospitality industry, such that the effect is stronger when NFHI levels are low compared to when NFHI levels are high.

Hypothesis 4b: NFHI negatively moderates the indirect effect of employee-robot rapport on workplace loneliness in the tourism and hospitality industry, such that the indirect effect is stronger when NFHI levels are low compared to when NFHI levels are high.

Moreover, for employees with high NFHI, the social presence of robots may be more effective in enhancing interpersonal closeness with colleagues. These individuals may feel a greater need for human connection and social support in the workplace (Ayazlar & Güzel, 2014; Ozcelik & Barsade, 2018). Drawing from the social presence theory, when service robots exhibit a high degree of social presence, they can potentially generate a more engaging and collaborative working environment, which in turn encourages employees with high NFHI to develop closer connections with their colleagues (Christou et al., 2020). This is particularly relevant in the tourism and hospitality industry, where team cohesion and interpersonal relationships play a crucial role in service delivery and employee well-being. Based on these arguments, we propose the following hypotheses:

Hypothesis 5a: NFHI positively moderates the relationship between the social presence of robots and interpersonal closeness in the tourism and hospitality industry, such that the effect is stronger when NFHI levels are high compared to when NFHI levels are low.

Hypothesis 5b: NFHI positively moderates the indirect effect of interpersonal closeness on workplace loneliness in the tourism and hospitality industry, such that the indirect effect is stronger when NFHI levels are high compared to when NFHI levels are low.

The proposed research model, incorporating the hypothesized relationships, is depicted in Figure 1.

<Insert Figure 1 about here>

3. Overview of the empirical studies

This research consists of a set of experimental designs (Study 1a & 1b) and a two-wave questionnaire (Study 2). Study 1a aims to examine the main effect between robot social presence and lonliness, initially employing a scenario-based experimental design, wherein tourism and hospitality employees were recruited via the Credamo platform. Participants were asked to read a scenario (depicting high or low levels of the social presence of robots) and to assess their perceived loneliness in that workplace. Study 1b then elucidates the mediating effects by employing a naturalistic experimental approach. It investigates two hotels that each adopt different service robot application strategies. The study collects employee evaluations of the social presence of robots, employee-robot rapport, interpersonal closeness, and workplace loneliness. Conducted in two waves, Study 2 employs an online questionnaire survey to further explore the main effects, mediating effects, and moderating effects. The integration of experiments and questionnaire survey enhances the external and internal validity of the research findings and further strengthens the rigor of the empirical testing conducted (Liu et al., 2021).

4. Study 1

4.1 Study 1a: A scenario-based online experiment

4.1.1 Stimulus materials, procedure and sampling

Study 1a examines the main effect through an online scenario experiment. A between-subjects design was adopted, where participants were randomly assigned to one of two experimental conditions (low vs. high robot social presence). Studies suggested that the anthropomorphism cues would lead to both the perceptions of anthropomorphism and social presence to a large extent (Araujo, 2018; Go & Sundar, 2019). However, anthropomorphism refers to the extent to which the robot seems human-like, whilst social presence involves that how much the robot was considered to be a “real” person (Ciechanowski, 2019). Having referred to existing studies and operational definitions of the social presence of robots (e.g., Kim et al., 2022), we manipulated both the external characteristics (e.g., appearance) and internal functional (e.g., communication ability) levels of the robots (see Appendix 1). Participants were instructed to read the scenario carefully and to imagine themselves as the employee in the given scenario.

After reading the experimental material, participants were asked to answer questions related to the independent and dependent variables. The social presence of robots was measured using three items from Heerink et al. (2010). Workplace loneliness was measured using four items from Lam & Lau (2012). To ensure the validity of our experiment, participants were asked to rate the realism (M= 6.15, SD= 0.89), clarity (M= 6.19, SD= 0.69), and understandability (M= 6.15, SD= 0.83) of the experimental materials. In addition to demographic information, all measurements were made using a 7-point Likert scale (1 representing strongly disagree, 7 representing strongly agree).

Before starting the formal experiment, a pretest was conducted. A total of 50 full-time employees from the tourism and hospitality industries were recruited through the

Credamo online platform and randomly assigned to one of the two experimental conditions to complete the pretest. The analysis results of ANOVA showed that there was a significant difference in the scores of the social presence of robots between the two groups ($M_{\text{high presence group}}$= 4.93, $M_{\text{low presence group}}$= 2.94, $F(1,48)$= 28.723, $p<$ 0.001), indicating that our manipulation was effective. We then proceeded with the main study.

Study 1a recruited 120 full-time employees in the tourism and hospitality sector through Credamo. Participants who completed the survey were paid RMB 3 each. After excluding participants who did not pass the attention test, 115 respondents successfully completed the survey, of which 30.4% were male. The average age was 30.59 years (*Max*= 58, *Min*= 19, *SD*= 8.14). Participants' educational levels were categorized into four groups: high school and below (7.8%), college (19.1%), bachelor's degree (66.1%), and master's degree and above (7.0%). The participants were primarily from the hotel industry (60.9%) and the catering industry (30.4%).

4.1.2 Manipulation check and results

To assess the effectiveness of the operation, an ANOVA was conducted, and the results indicated that there were significant differences in participants' evaluations of the social presence of the robots ($M_{\text{low presence group}}$= 3.13, $M_{\text{high presence group}}$= 4.16, $F(1,113) = 14.571$, $p< 0.001$, α= 0.86). This suggests that the manipulation was successful.

As shown in Figure 2, the ANOVA revealed that there was a significant impact on workplace loneliness between the two experimental groups ($M_{\text{low presence group}}$= 3.83, $M_{\text{high presence group}}$= 3.32, $F(1,113) = 6.963$, $p< 0.01$, α= 0.71). Therefore, H1 was supported.

Although this scenario-based experiment confirmed that the social presence of robots has a significant impact on employee workplace loneliness, the design of the experiment may give rise to potential concerns about the authenticity of the simulated scenarios and the external validity of the research results. To address these limitations and to further explore the mediating effects of the social presence of robots on workplace loneliness, Study 1b was conducted.

<Insert Figure 2 about here>

4.2 Study 1b: A natural experiment

4.2.1 Comparison and selection of natural experimental settings

Natural experiments study phenomena without manipulating the major constructs, enabling valid causal inferences beyond statistical correlations (Li et al., 2024; Xie et al., 2022). Success requires selecting environments where conditions align with research objectives and where external factors remain consistent between experimental and control groups, allowing accurate measurement of variable impacts (Chen et al., 2011; Jordan et al., 2021; Leatherdale, 2019).

Following Chen et al. (2011), we used convenience sampling to select two comparable Grand Skylight hotels in Ganzhou, China in May 2023. The hotels match in department structure, room specifications, pricing, service culture, and staffing. They differ primarily in robot deployment: Hotel A's robots perform only deliveries, while Hotel B's robots offer interactive functions including lobby patrol and guest information services. Based on preliminary observations, these locations provided an ideal natural experimental setting with clear contrast in robot social presence while maintaining consistency in other variables.

4.2.2 Sampling, procedure and measurement

Study 1b recruited a total of 67 employees from the front desk, concierge, and housekeeping departments of two hotels (38 from Hotel A and 29 from Hotel B). As a reward, each participant who took part in this experiment received RMB 5. Of the total sample, 55.2% were female, and 19.4% were between the ages of 18-25 years and 59.7% between 26-35 years. More than 60% had a college or associate degree. Participants were mainly from three departments: the front desk (38.8%), concierge (35.8%), and housekeeping (25.4%). Frontline employees constituted 86.6% of the sample, and more than 80% had three years or less of working experience.

Participants evaluated robot social presence, workplace loneliness, employee-robot rapport, and interpersonal closeness based on their direct workplace experiences. Due to shift work, questionnaire collection was completed within three days at each hotel, with synchronized timing between locations to minimize sampling bias.

Consistent with Study 1a, Study 1b employed the same scales for the independent and outcome variables. Employee-robot rapport was measured through the three-item scale adapted from Fernandes and Oliveira (2021) and Qiu et al. (2020), while interpersonal closeness was assessed using seven items from the instrument by Vangelisti and Caughlin (1997). All variables were measured using a 7-point Likert scale (1 representing strongly disagree, 7 representing strongly agree). The control variables in this study were the demographic variables of employees (gender, age, education level, job income, work experience, daily interaction frequency).

4.2.3 Manipulation check and results

Our manipulation of the social presence of robots had a significant effect on employee perceptions ($M_{\text{high presence group}}$= 4.98, $M_{\text{low presence group}}$= 3.94, $F(1, 65) = 9.025$, $p< 0.01$, $\alpha= 0.94$), confirming the effectiveness of our manipulations. We found the main effect of the social presence of robots to be significant, with employees who perceived higher levels of robot social presence were experiencing lower degrees of workplace loneliness ($M_{\text{highpresence group}}$ = 2.48, $M_{\text{low presence group}}$= 3.59, $F(1,65)$= 66.585, p< 0.001, α= 0.76). This finding supports H1.

The results also indicated that participants who perceived higher levels of social presence in robots expressed more employee-robot rapport ($M_{\text{high presence group}}$= 5.38, $M_{\text{low presence group}}$= 4.25, $F(1,65)$ = 15.177, p< 0.001, , α= 0.91). However, there was no significant difference in interpersonal closeness between the high and low robot social presence groups ($M_{\text{high presence group}}$= 5.49, $M_{\text{low presence group}}$= 5.28, $F(1,65)$= 0.660, p= 0.420> 0.05, , α= 0.93). Thus, H2a was supported, while H3a was not supported.

A bootstrap method (Hayes, 2013) was utilized to examine the mediating effect of employee-robot rapport and interpersonal closeness (PROCESS, Model 4, 5000 samples). The results indicated that the mediating effect of employee-robot rapport was significant (β= -0.103, *Boot SE*= 0.059, *LLCI*= -0.2757, *ULCI*= -0.0236, not including 0). The mediating effect of interpersonal closeness was not significant (β= 0.018, *LLCI*= -0.0183, *ULCI*= 0.0976, including 0), supporting H2c, while H3c was not supported. Furthermore, the regression coefficients of employee rapport on loneliness (β= -0.225, p< 0.01) was significant, but the effect of interpersonal closeness on loneliness was insignificant (β= 0.072, p> 0.05). Thus, H2b was supported but not H3b.

<Insert Figure 3 about here>

4.3 Discussion

Studies 1a and 1b demonstrate that high social presence in robots reduces workplace loneliness, supporting H1. Study 1b also confirms the mediating role of robot-employee rapport, while interpersonal closeness is not significant. This may be due to the high customer orientation and collaboration culture in the two high-end hotels studied, where environmental and institutional factors (e.g., corporate culture/climate, Liu and Xie, 2024) dominate, leading to uniformly high intimacy levels. To further explore mediating and moderating effects, Study 2 was conducted with a larger sample.

5. Study 2

5.1 Data collection and procedure

From July to December 2023, Study 2 employed convenience sampling for data collection, with questionnaire surveys issued through offline and online channels. We selected seven hotels in Beijing, Guangzhou, Shenzhen, Zhuhai, Ganzhou, and Shantou that have already implemented service robots for an offline survey. For the online survey, we hired a data collection company to gather additional data from employees in the tourism and hospitality industry. This study required participants to be from companies which used service robots, and for participants to be engaging with service robots in their daily work. As an initial step, participants were first asked to recall and describe the functions of service robots in their workplace before beginning to answer the survey. A total of 712 employees (offline: 412, online: 300) from hotels, restaurants, tourist destinations, and travel agencies participated in the first round of surveys. One month later, 466 respondents (offline: 281, online: 185) out of the original 712 participated in the second round of surveys, making for a matching rate of 65.4%[1]. Following a screening process, 31 invalid responses were excluded (e.g., those not meeting the research requirements or failing attention check questions), resulting in 435 valid responses in total.

The collection of data at multiple time points has the advantage of reducing potential common method biases (Podsakoff et al., 2012). This study collected data at two time points, with a month separating each point. At the first time point (T1), participants answered questions relating to measurements of the social presence of robots, their own need for human interactions, and provided demographic information about themselves. At the second time point (T2), participants self-evaluated their levels of employee-robot rapport, interpersonal closeness, workplace loneliness, and the degree to which their emotions were positive. To ensure the accurate matching of data between the two time points, all participants were required to provide the last four digits of their mobile phone numbers. Participants who successfully completed both rounds of surveys received a reward of RMB 10 (RMB 3 for successful participation in the first round and RMB 7 for successful participation in the second round).

Table 2 provides the demographic information of the participants, of whom the majority were working in hotels (49.4%), restaurants (26.7%), and tourist destinations, travel agencies and the other hospitality business (19.8%). Of the 435 participants, 44.6% were male and the age distribution was as follows: 18-25 years (12.2%), 26-35 years (60.9%), and 36-45 years (24.1%). Most participants (66.2%) held bachelor’s degrees, followed by those with associate degrees or diplomas (23.7%). In terms of positions, the sample primarily comprised frontline employees

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[1] A total of 412 employees from seven hotels under a certain brand in China participated in the first round of surveys through offline channels. Via online channels, recruitment was conducted through an online platform, Credamo, targeting 300 employees from tourism service enterprises such as hotels, restaurants, scenic spots, and shopping malls for the first round of surveys. One month later, these participants were invited again for another survey round. The results showed that 281 responses were collected from offline channels, with a response rate of 76.6%, while 185 responses were collected from online channels, with a response rate of 45.8%.

(28.0%), assistant managers (39.8%), and department managers (28.7%). With respect to work experience 52.2% had between 1-3 years and 29.2% had between 4-6 years; Income-wise, 26.9% of employees had a monthly income between 5001-7000 RMB, and 37.5% had a monthly income between 7,001-10,000 RMB.

<Insert Table 2 about here>

5.2 Measurement

The scales for all the variables were sourced from existing literature and underwent a translation-back translation procedure. Two researchers in hospitality management were invited to conduct proofreading for two versions of the scales. Additionally, pre-surveys were conducted with a small group of respondents to ensure the validity of the scales. All research variables were measured using 7-point Likert scales, with response options ranging from strongly disagree (1) to strongly agree (7).

The social presence of service robots was measured using a three-item scale developed by Heerink et al. (2010), while workplace loneliness was assessed using a 16-item scale developed by Lam & Lau (2012). Employee-robot rapport was measured with a three-item scale adapted from Fernandes and Oliveira (2021) and Qiu et al. (2020), while interpersonal closeness was assessed using seven items from Vangelisti and Caughlin (1997). Finally, the need for human interaction (NFHI levels) was measured using a four-item scale from Dabholkar and Bagozzi (2002). Building on prior research on service robots and employee behavior (Liang et al., 2022; Liu et al., 2024; Yu et al., 2022), we controlled for participants' demographics (e.g., gender, age, education, income, position, work experience, and industry type), daily robot contact frequency, and positive emotions, as these factors may influence human-robot interaction effectiveness and loneliness (Dedeoğlu et al., 2024; Tang et al., 2023). The measurement of positive emotions utilized a 5-item scale from Mackinnon et al. (1999). Appendix 2 contains all the details of the instruments used to measure the variables.

5.3 Procedural remedies and analytic methods

Procedural and statistical controls were employed in this study. Procedurally, we conducted a two-wave questionnaire survey, ensuring anonymity and confidentiality to allow participants to answer freely and to alleviate potential common method bias (Kock, 2021). Statistically, we first conducted t-tests on the demographic characteristics of the lost (respondents who had participated in the first round of surveys but not the second round) and final samples. The results revealed no significant differences between the lost and final samples in most demographic characteristics: gender (t_{gender}= -1.25, n.s.), age (t_{age}= 0.71, n.s.), education ($t_{education}$= 0.94, n.s.), position ($t_{position}$= -1.59, n.s.), and work experience ($t_{work\ experience}$= 0.80, n.s.). In other words, the lost samples between T1 and T2 did not cause serious sample bias. Furthermore, the results of Harman's single-factor analysis showed that the main factor only explained 33.19% of the variance, meeting the requirement of less than half of the cumulative explained variance (69.19%). This indicates that common method bias was not a major issue in this study (Podsakoff et al., 2012).

In the subsequent analysis, we employed the Partial Least Squares Structural Equation Modeling (PLS-SEM) path modeling method, using Smart PLS 3.0 software to test all hypotheses (Hair et al., 2017). PLS-SEM is based on a variance-based SEM comprehensive system and enables the use of indicators to measure unobservable variables without the assumption of normality. This method is particularly suitable for the convenience sampling approach of this study. Next, we conducted confirmatory factor analysis using the Consistent PLS algorithm. We then used Consistent PLS bootstrapping to test the causal relationships of the proposed hypotheses (main effects, mediating, and moderating effects), followed by a further analysis of the moderated mediation effects using SPSS-Macro PROCESS.

5.4 Results

5.4.1 The assessment of the measurement model

The measurement model was evaluated using the SmartPLS 3.0 algorithm. As shown in Table 3, all loading values range between 0.521 and 0.940 (the standard values were all greater than 0.5, see more details in Appendix 2). Cronbach' s α values ranged between 0.77 and 0.95 (greater than the standard value of 0.7), and all CR values were above 0.70, indicating acceptable internal consistency reliability of the measurement model. Moreover, all the AVE values were greater than 0.40, indicating satisfactory convergent validity of the measurement model. In Table 2, the square roots of all AVEs are higher than the corresponding correlations, consistent with established research standards (Fornell & Larcker, 1981). Additionally, all HTMT ratios are below the threshold of 0.90 (Henseler et al., 2015), indicating satisfactory discriminant validity of the measurement model.

<Insert Table 3 about here>

5.4.2 The assessment of the structural model

Before testing our hypotheses, we evaluated the explanatory and predictive capabilities of the structural model using the coefficients of determination (R^2), effect sizes (f^2), and cross-validated redundancy (Q^2), referring to Hair et al. (2017). The R^2 values for employee-robot rapport, interpersonal closeness, and workplace loneliness are 0.721, 0.376, and 0.316 respectively, as detailed in Table 4. According to Cohen's (1988) guidelines, f2 values of 0.02, 0.15, and 0.35 represent weak, moderate, and strong effects respectively for the corresponding exogenous variables. In the research model, the effects of the social presence of robots on workplace loneliness (f^2=0.162), employee-robot rapport (f^2=0.268), and interpersonal closeness (f^2=0.411) are strong, while the effect of positive emotions on workplace loneliness is strong as well. The effects of the remaining paths range from moderate to weak, with f^2 values ranging from 0.001 to 0.148. Finally, Stone-Geisser's Q^2 values are obtained, with workplace loneliness, employee-robot rapport, and interpersonal closeness being 0.397, 0.312, and 0.196 respectively. These values indicate acceptable predictive capabilities of the corresponding endogenous constructs (Geisser, 1974). The goodness-of-fit index (GOF) for this structural model is 0.564, exceeding the large effect value of 0.36 proposed by Wetzels et al. (2009), thus demonstrating a good fit of the model.

<Insert Table 4 about here>

5.4.3 Hypotheses testing

5.4.3.1 The direct effects

To examine the direct effects among the variables, this study employed path analysis and utilized the Bootstrap procedure in Smart PLS 3.0 (bootstrap samples=5000). The results of the path analysis (see Table 5) indicate that, after controlling for control variables (gender, age, education, position, work experience, income, industry, daily contact frequency and positive emotions), the effect of the social presence of robots on workplace loneliness is significant (β=-0.285, p< 0.001), supporting H1. The positive impact of the social presence of robots on employee-robot rapport is also significant (β=0.491, p< 0.001), as is the negative effect of employee-robot rapport on workplace loneliness (β=-0.161, p< 0.001). As such, H2a and H2b are supported. Meanwhile, the positive effect of the social presence of robots on interpersonal closeness is significant (β=0.517, p< 0.001), as is the negative effect of interpersonal closeness on workplace loneliness (β=-0.274, p< 0.01), providing support for H3a and H3b.

<Insert Table 5 about here>

5.4.3.2 The mediating effects

To test the mediation effects, we conducted mediation analysis using Variance Accounted For (VAF) in PLS-SEM (bootstrap samples= 5000). This method requires that the indirect effect a × b must be significant, and then determines the presence and specific type of mediation based on the VAF values. If the VAF value is greater than 0.8, there is full mediation. If the VAF value is between 0.2 and 0.8, there is partial mediation. If the VAF value is less than 0.2, there is no mediation (Hair et al., 2017). The mediation effect of social presence on workplace loneliness through employee-robot rapport is significant ($\beta_{\text{indirect effect}}$= -0.079, *SE*= 0.023, p< 0.01, *VAF*= 0.356), indicating partial mediation, supporting H2c. Similarly, the mediation effect of the social presence of robots on workplace loneliness through interpersonal closeness is also significant ($\beta_{\text{indirect effect}}$= -0.142, *SE*= 0.057, p< 0.05, *VAF*= 0.639) and indicative of partial mediation, supporting H3c.

5.4.3.3 The moderating effects

The results of the path analysis (as shown in Table 5) indicate that the interaction effect between the social presence of robots and the need for human interactions on employee-robot rapport is significantly negative (β= -0.189, p< 0.05). Conversely, the interaction effect between the social presence of robots and the need for human interactions on interpersonal closeness is significantly positive (β= 0.161, p< 0.01). To further explore the moderating effects, we conducted simple slope analyses on these two interaction terms. As depicted in Figure 4a, when the need for human interactions is low, the impact of the social presence of robots on employee-robot rapport is significant (β= 1.034, t= 18.878, p< 0.001), and this relationship becomes weaker when the need for human interactions is high (β= 0.482, t= 8.800, p< 0.001). This indicates that the need for human interactions negatively moderates the relationship between the social presence of robots and employee-robot rapport, thus supporting H4a.

Similarly, as shown in Figure 4b, when the need for human interactions is high, the relationship between the social presence of robots and interpersonal closeness is significant (β= 0.511, t= 16.159, p< 0.001). However, if the need for human interactions is low, this significant relationship becomes weaker (β= 0.335, t= 10.594, p< 0.001). This indicates that the need for human interactions positively moderates the relationship between the social presence of robots and interpersonal closeness, supporting H5a.

<Insert Figure 4 about here>

5.4.3.4 The moderated mediating effects

To test the moderated mediation proposed in hypothesis 4, the SPSS-Macro PROCESS (Model 7) moderated mediation method (Hayes, 2013) was employed to compute the indirect effects and their confidence intervals at different levels of the moderator (bootstrapping times = 5000). The results (shown in Table 6) indicate that when the need for human interactions is lower, the indirect effect of the social presence of robots on workplace loneliness through employee-robot rapport is stronger ($\beta_{\text{indirect effect when NFHI is low}}$= -0.078, confidence interval is [-0.1935, -0.0382]; $\beta_{\text{indirect effect when NFHI is high}}$= -0.025, confidence interval is [-0.0752, -0.0018]), suggesting that the need for human interactions negatively moderates the mediating strength of employee-robot rapport, supporting H4b. However, when NFHI levels are higher, the indirect effect of the social presence of robots on workplace loneliness through interpersonal closeness is significant ($\beta_{\text{indirect effect when NFHI is high}}$ = -0.097, confidence interval is [-0.1639, -0.0539]). When NFHI levels are low, this indirect effect ($\beta_{\text{indirect effect}}$=-0.028, confidence interval is [-0.1200, 0.0167]) includes 0, indicating insignificance, suggesting that the need for human interactions positively moderates the mediating strength of interpersonal closeness, thus supporting H5b.

<Insert Table 6 about here>

6. Discussion and conclusion

This study set out to address significant gaps in our understanding of how the social presence of service robots affects employee well-being, particularly workplace loneliness, in the tourism and hospitality industry. The research aimed to explore the underlying mechanisms. Through a scenario experiment, a natural experiment, and a two-stage questionnaire survey, the empricial results revealed that robot social presence significantly alleviates workplace loneliness among tourism and hospitality employees. The study uncovered two key mediating mechanisms and identified an important moderating factor. The mediating mechanism involved two aspects of relationship quality: employee-robot rapport and interpersonal closeness, both of which partially mediate the main effects. NFHI negatively moderates the mediating strength between social presence and employee-robot rapport, while positively moderating the mediating strength between social presence and interpersonal closeness. Moreover, NFHI suppressed the strength of the indirect path of employee-robot rapport and promoted the strength of the mediating path of interpersonal closeness. These results contribute valuable insights to the ongoing debate about the efficacy of robot interactions in addressing social needs in workplace contexts.

6.1. Theoretical contributions

This research offers several theoretical contributions. First, it extends the social presence theory (Short et al., 1976; Biocca et al., 2003) by proposing a novel framework to examine how robots' social presence reduces workplace loneliness. Originally developed to understand technologically mediated human interactions, social presence theory has largely focused on digital environments involving human actors (Short et al., 1976; Biocca et al., 2003). Early research indicated that human-robot interactions often involve uncertainty and reduced warmth compared to human-human interactions (Edwards et al., 2016). Our findings challenge this perspective by demonstrating that service robots can act as "technological companions", offering emotional support and companionship to employees. This reframes established notions of social actors in organizational settings (van Doorn et al., 2017; Kim et al., 2022). Moreover, previous studies have primarily explored robots' operational and customer-oriented roles (Belanche et al., 2020; Tussyadiah, 2020), our research shifts the focus to employee psychological well-being, addressing workplace loneliness. Our findings show the potential of robots to complement human-centric approaches, thus expanding the scope of social presence theory (Jung & Yoon, 2022; Kuriakose et al., 2023).

Second, we advance social presence theory by uncovering two distinct but complementary mechanisms through which robots' social presence transforms workplace dynamics. While previous research like Kim et al. (2022) and Qiu et al. (2020) typically focused on single-pathway effects or examined employee-robot rapport and interpersonal relationships separately, our model demonstrates how these pathways operate simultaneously. The first pathway shows that robots with high social presence can directly reduce loneliness by developing meaningful rapport with employees, and extending prior works about robots providing social support (Odekerken-Schröder et al., 2020). The second pathway reveals an often neglected effect where robots enhance human-to-human connections, challenging earlier assumptions that technology might reduce human interaction (van Doorn et al., 2017), while supporting technology fostering human relationships (Christou et al., 2020). What makes our dual-pathway model particularly valuable is its demonstration that these pathways are not merely parallel but complementary, advancing beyond findings about collaborative environments by showing how technology can enhance both direct and indirect social connections (Liang et al., 2022). Thus we expand our understanding beyond the concept of robots as "technological companions" (Jones et al., 2021) to show how they can simultaneously serve as both companions and facilitators of human relationships.

Finally, our research makes a significant theoretical contribution by uncovering novel boundary conditions of NFHI in workplace settings, challenging and extending conventional wisdom about human-robot interactions. While previous research has primarily examined NFHI in customer-technology interactions, establishing that high-NFHI individuals generally avoid technological encounters (Dabholkar & Bagozzi, 2002; Hu et al., 2021), our findings reveal a more sophisticated and paradoxical dynamic in employee-robot relationships. Consistent with established patterns showing that low-NFHI individuals tend to seek technological interactions (Fernandes & Oliveira, 2021; Wirtz et al., 2018), we find that low-NFHI employees form stronger direct bonds with robots. However, more surprisingly, we discover that high-NFHI employees - who typically resist technological interaction (Kelly et al., 2019) - experience improved interpersonal relationships with colleagues in robot-present environments. This dual effect is particularly significant in the tourism and hospitality industry (Min et al., 2015; Park & Kim, 2019), showing how the same technological intervention can simultaneously satisfy both low-NFHI employees' preference for machine interaction and high-NFHI employees' desire for human connection. This extends social presence theory by revealing how its mechanisms operate differently for high and low NFHI employees in workplace settings, moving beyond the traditional view of NFHI as a simple moderator of technology acceptance to a more sophisticated understanding of how individual differences shape workplace robotics adoption.

6.2. Practical implications

Our research offers significant practical insights for managers implementing service robots. First, our findings suggest that managers should approach robot deployment not merely as an operational decision but as a strategic tool for enhancing employee psychological wellbeing. Traditional implementation strategies have focused primarily on operational efficiency and customer service metrics, overlooking the potential for robots to address workplace loneliness and enhance employee satisfaction (Belanche et al., 2020; Tussyadiah, 2020). Managers should design workplace layouts and interaction protocols that deliberately facilitate both human-robot and human-human interactions. This includes creating dedicated spaces for collaborative work between employees and robots, while ensuring these spaces also promote informal employee gatherings and social interactions. Organizations should develop comprehensive training programs that frame robots as collaborative partners rather than just operational tools, helping employees understand how to leverage robotic presence for both task completion and social support (van Doorn et al., 2017).

The dual-pathway model uncovered in our research suggests managers need to cultivate a hybrid social environment where technological and human interactions complement each other. This requires careful attention to both direct and indirect social benefits of robot implementation. Managers should create structured opportunities for meaningful employee-robot rapport building while simultaneously designing workplace activities that leverage robot presence to enhance human connections. For example, collaborative tasks involving both robots and multiple employees can foster team bonding while building technological comfort. Organizations should develop comprehensive metrics that capture both the direct benefits of employee-robot interactions and the indirect benefits of enhanced human connections facilitated by robotic presence (Kuriakose et al., 2023).

Our findings about NFHI's boundary conditions reveal the importance of personalized implementation approaches. Managers must recognize that employees differ significantly in their comfort with and preference for technological interaction. This necessitates developing differentiated onboarding processes and flexible work arrangements that allow employees to adjust their level of robot interaction based on individual preferences (Wirtz et al., 2018; Kelly et al., 2019). For instance, high-NFHI employees might benefit from gradual exposure to robot interactions, with initial emphasis on how robots can facilitate human connections. Conversely, low-NFHI employees might appreciate early opportunities for direct robot interaction and collaboration. Organizations should consider implementing adaptive robot interfaces that can accommodate these varying preferences, allowing employees to customize their interaction patterns while maintaining operational efficiency (Jung & Yoon, 2022).

Success in implementing these strategies requires systematic assessment of robot integration's impact on workplace dynamics. Human resource departments should incorporate both operational metrics and social indicators into their evaluation frameworks, measuring traditional performance alongside employee-robot rapport and team cohesion. While our findings demonstrate robots' potential to enhance workplace connections, organizations must establish clear guidelines that maintain a balance between technological efficiency and meaningful human interactions. Through careful monitoring and balanced implementation, organizations can optimize robotic integration while creating an environment that promotes both productive collaboration and social wellbeing (Odekerken-Schröder et al., 2020; Jones et al., 2021).

6.3. Limitations and future research directions

This research has several limitations. Firstly, the samples are drawn from the tourism and hospitality industry in China. Future researchers may select samples from other countries to test the robustness of the conclusions of this study and to examine potential cross-cultural effects. Secondly, Study 1 utilized experimental methods. Although we verified the main effects, neither Study 1a nor Study 1b effectively revealed the two mediating effects. Study 1a only explored the main effects through scenario questionnaires, while Study 1b only verified the causality between the social presence of robots, employee-robot rapport and workplace loneliness. Study 1b also indicated that the mediating effect of interpersonal closeness is not significant. Future research may undertake observational methods and interviews to further explore the internal and mediating mechanisms of workplace loneliness. Thirdly, this study only focused on an individual-level conditional factor: the need for human interaction. Researchers in the future may consider exploring boundary conditions at the organizational level (e.g., organizational culture) and societal level (e.g., the pace of AI development).

In addition to this, it is also suggested that future researchers to focus on the topic of employee-robot interactions and to explore the impact of employee-robot interactions on customer evaluations. Other methodological approaches may also be used to explore the issue of employee-robot interactions beyond the questionnaire surveys and experimental methods described in this paper. Future researchers may consider employing the experience sampling method to explore daily fluctuations in human-robot interactions or analyze the work behavior trajectories of employees and service robots through devices such as signal detection.

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Appendix 1

Study 1a Experimental stimulus and measurement

Low robot social presence

Mr./Miss Allen is a front desk employee at Hotel Y. One day, when s/he arrived at work, Allen found that the hotel had purchased a service robot and designated it as an assistant to human employees. The robot can deliver items, but cannot communicate with Mr./Miss Allen verbally. Allen would often issue commands by clicking buttons to get the robot to complete tasks.

High robot social presence

Mr./Miss Allen is a front desk employee at Hotel Y. One day, when s/he arrived at work, Allen found that the hotel had purchased a service robot and designated it as an assistant to human employees. The robot can deliver items and communicate with Mr./Miss Allen verbally. Allen would often issue oral commands to get the robot to complete tasks.

Please imagine that you are Allen based on the above scenario and answer the following questions.

Robot social presence

When interacting with the robot, I would feel like I am talking to a real person

I would imagine the robot to be a living creature

I would feel sometimes the robot seems to have real feelings

Workplace Loneliness

I would not feel satisfied with the human-robot relationships I have at work

I experience a general sense of emptiness when I am at work

There is not any sense of camaraderie from robots in my workplace

The robot would make me feel as if I have a new social partner

Study 1b Measurement

Robot social presence

When interacting with the robot, I felt like I am talking to a real person

I can imagine the robot to be a living creature

Sometimes the robot seems to have real feelings

Workplace Loneliness

I feel satisfied with the human-robot relationships I have at work

I experience a general sense of emptiness when I am at work

There is not any sense of camaraderie from robots in my workplace

The robot would make me feel as if I have a new social partner (R)

Employee-robot rapport

The robot relates well to me

I think there is a "bond" between the robot and myself

I would actively respond to questions by the robot

Interpersonal closeness

How close are you to your colleagues?

How much do you like people around your colleagues?

How often do you talk about personal things with your colleagues?

How important is your colleagues opinion to you?

How satisfed are you with your relationship with your customers?

How much do you enjoy spending time with your customers?

How important is your relationship with your customers?

Apendix 2

The measurement in study 2

Variable	Label	Measurement items	Loading
Social presence of robots	SP1	When interacting with the robot I felt like I am talking to a real person.	0.938
	SP2	I can imagine the robot to be a living creature.	0.940
	SP3	Sometimes the robot seems to have real feelings.	0.938
Workplace loneliness	WL1	I often feel abandoned by my coworkers when I am under pressure at work	0.739
	WL2	I often feel alienated from my coworkers	0.789
	WL3	I feel myself withdrawing from the people I work with	0.786
	WL4	I often feel emotionally distant from the people I work with	0.786
	WL5	I feel satisfied with the relationships I have at work (R)	0.755
	WL6	There is a sense of camaraderie in my workplace (R)	0.783
	WL7	I often feel isolated when I am with my coworkers	0.763
	WL8	I often feel disconnected from others at work	0.801
	WL9	I experience a general sense of emptiness when I am at work	0.749
	WL10	I have social companionship/fellowship at work (R)	0.697
	WL11	I feel included in the social aspects of work (R)	0.829
	WL12	There is someone at work I can talk to about my day to day work problems if I need to (R)	0.665
	WL13	There is no one at work I can share personal thoughts with I want to	0.622
	WL14	I have someone at work I can spend time with on my breaks if I want to (R)	0.738
	WL15	I feel part of a group of friends at work (R)	0.687
	WL16	There are people at work who take the trouble to listen to me	0.764
Employee-robot rapport	ERR1	The robot relates well to me	0.917
	ERR2	I think there is a “bond” between the robot and myself	0.927
	ERR3	I would actively respond to questions by the robot.	0.904
Interpersonal closeness	IC1	How close are you to your colleagues?	0.828
	IC2	How much do you like people around your colleagues?	0.850
	IC3	How often do you talk about personal things with your colleagues?	0.800
	IC4	How important is your colleagues opinion to you?	0.595

	IC5	How satisfed are you with your relationship with your customers?	0.847
	IC6	How much do you enjoy spending time with your customers?	0.860
	IC7	How important is your relationship with your customers?	0.770
Need for human interaction	NHFI1	At work, human contact in providing services makes the process enjoyable for me.	0.521
	NHFI2	I like interacting with the person who receives the service.	0.789
	NHFI3	Personal attention by the customer/colleague is very important to me.	0.538
	NHFI4	It bothers me to use a machine when I could talk to a person instead.	0.879
Positive emotions	PE1	During the recent period of work, I am inspired	0.820
	PE2	During the recent period of work, I am alert	0.627
	PE3	During the recent period of work, I am excited	0.844
	PE4	During the recent period of work, I am enthusiastic	0.844
	PE5	During the recent period of work, I am determined	0.841

Figures and tables

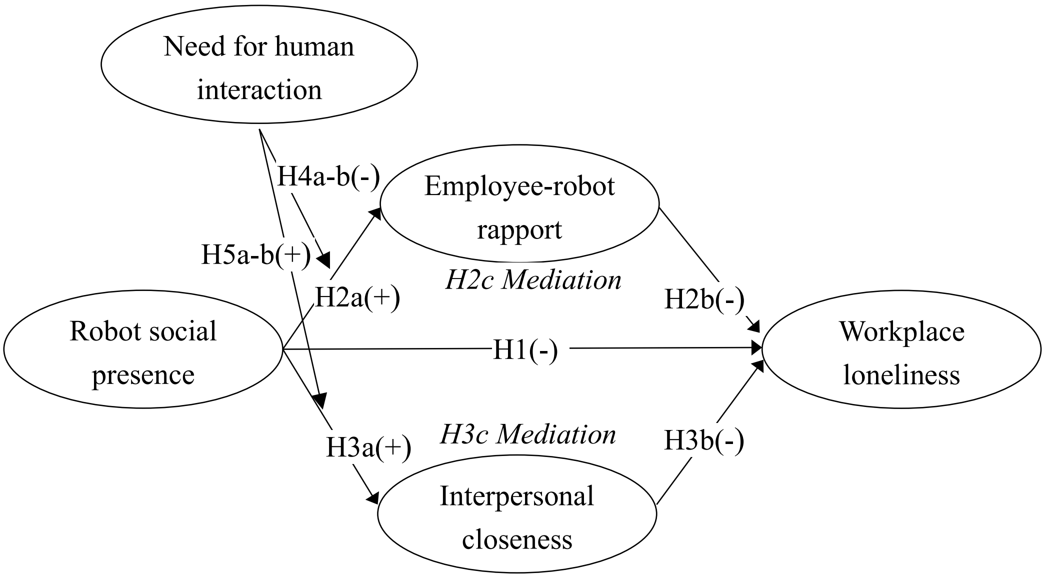

Figure 1 The research model

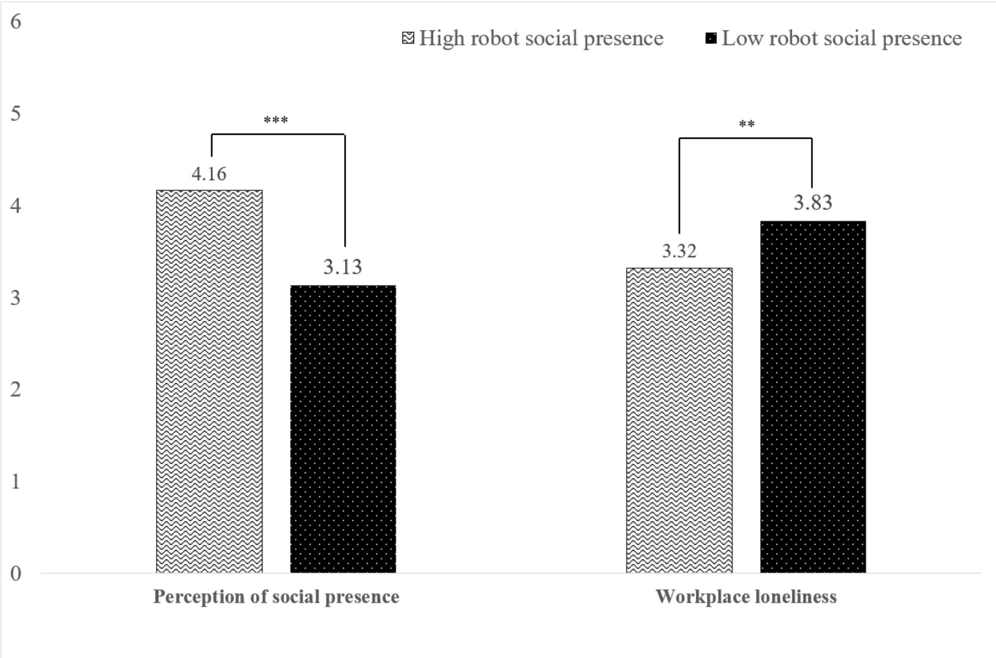

Figure 2 Comparison results of mean values in Study 1a

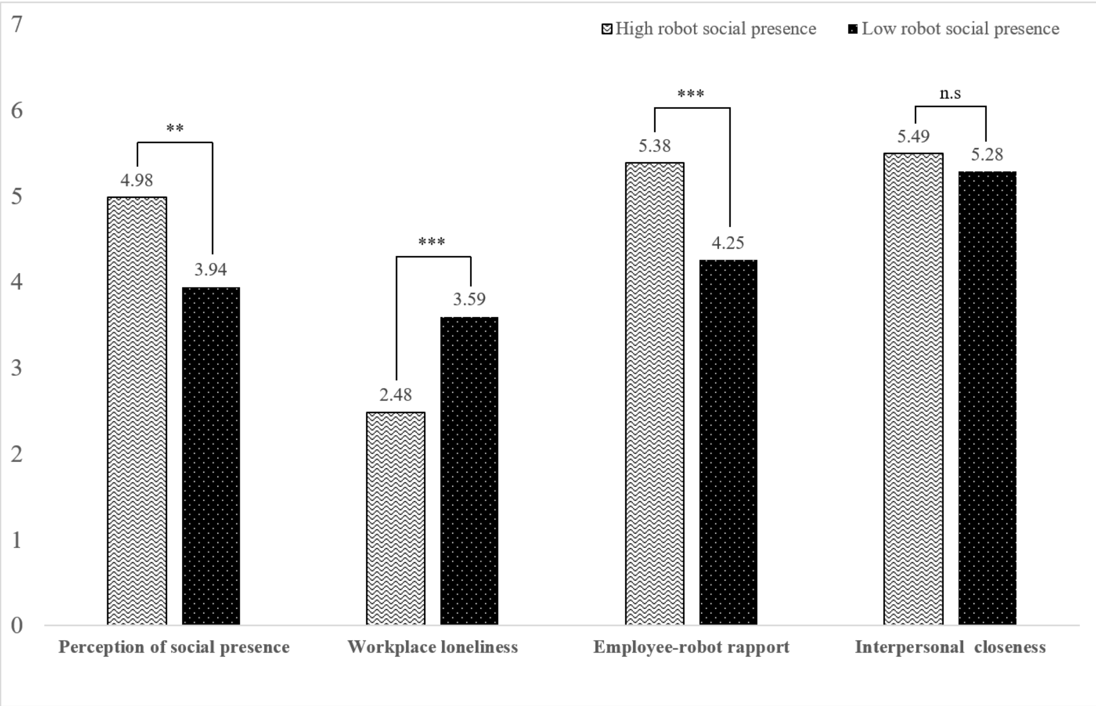

Figure 3 Comparison results of mean values in Study 1b

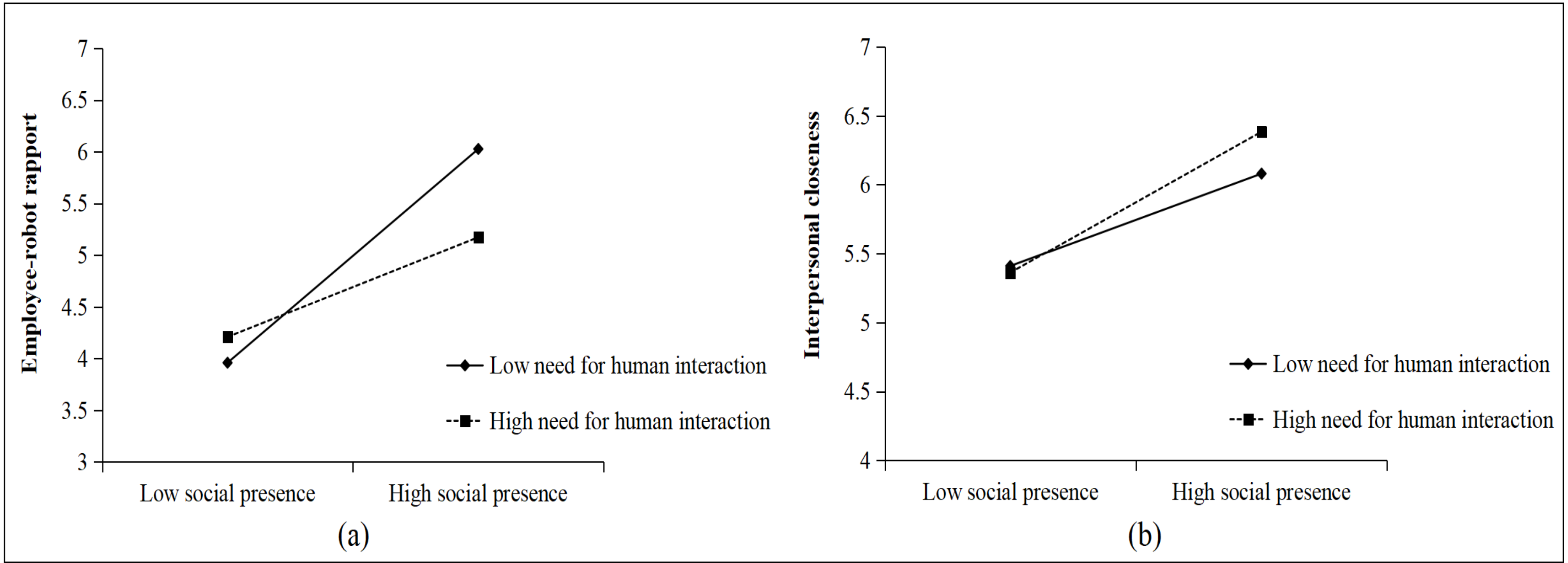

Figure 4 The moderating effects of the need for human interaction

Table 1 Summary of studies on the impacts of service robots on employees in tourism and hospitailty

DV type	Effect	IV	DV	Context	Method	Authors (year)
Acceptance	Positive	Robot affordance	Robot usage intention	Hotel	Experiment	Leung et al. (2023)
Acceptance	/	Robots' and employees' characteristics	Employees' willingness to seek help from robots	Hotel	In-depth interviews	Lin et al. (2024)
Acceptance	Both	Technological, organizational, and environmental factors	Robot usage intention	Hotel	Survey	Pizam et al. (2022)
Performance	Negative	AI awareness	Job burnout, career competencies	Hotel	Survey	Kong et al.(2021)
Performance	Negative	Perceived job insecurity	Turnover intention	Hotel	Mixed methods	Koo et al.(2021)
Performance	Negative	AI awareness	Turnover intention	Hotel	Survey	Li et al.(2019)
Performance	Negative	Employees' perceptions (perceived advantages of robots, previous experience with robots,the social skills of robots, robot awareness)	Robot-induced unemployment	Hospitality	Survey	Parvez et al.(2022)
Performance	Negative	Robots' human-likeness	Turnover intention	Accommodation	Experiment	Shum et al.(2024)
Performance	Negative	Adoption of service robots	Career identity	Tour, hotel and attraction	Experiment	Wang et al.(2024)
Performance	Positive	Employees' challenge-hindrance appraisals	Competitive productivity	Restaurant	Survey	Ding (2021)
Performance	Positive	AI-enabled anthropomorphic, entertainment, functional and information attributes	Service hospitableness	Hotel	Mixed methods	Qiu et al.(2022)

Performance	Positive	Employees' techsavviness and social skills	Turnover intention	Hotel	Survey	Yu et al.(2022)
Performance	Positive	Adoption of service robots	Knowledge management behaviour	Hotel	Survey	Guan et al.(2024)
Performance	Both	AI awareness	Service innovative behavior	Service industry	Survey	Liang et al.(2022)
Performance	Both	Employees' perceptions (i.e., perceived risk, perceived playfulness, performance expectancy, and effort expectancy)	Job crafting	Hotel	Survey	Song et al.(2022)
Performance	Both	Appraisal towards STARA awareness	Competitive productivity	Hospitality	Survey	Tan et al.(2024)
Performance	Both	Adoption of service robots	Turnover intention	Hotel	Survey	Zhang et al.(2023)
Performance & well-being	Negative	STAARA awareness	Job insecurity and mobility	Hotel	Experiment	Zhang & jin (2023)
Performance & well-being	Positive	Work autonomy	Service innovation behaviour and insomnia	Hotel	Survey	Li et al.(2024)
Well-being	**Positive**	**Robots' social presence**	**Employee loneliness**	**Hotel**	**Experiment & survey**	**This study**

Table 2 Demographic information in Study 2 (N= 435)

Item	Categories	Response	Percentage%
Gender	Male	194	44.6
	Female	241	55.4
Age	18-25 years old	53	12.2
	26-35 years old	265	60.9
	36-45 years old	105	24.1
	46-55 years old	11	2.5
	≥56 years old	1	0.2
Education	Middle school or lower	1	0.2
	High school	19	4.4
	College or associate degree	103	23.7
	Bachelor degree	288	66.2
	Master degree or higher	24	5.5
Position	Frontline employee	122	28.0
	Assistant manager	173	39.8
	Department manager	125	28.7
	Senior manager	15	3.4
Work experience	< 1 year	9	2.1
	1-3 years	100	23.0
	4-6 years	127	29.2
	7-9 years	114	26.2
	≥ 10 years	85	19.5
Monthly income (CNY)	≤ 3000	5	1.1
	3001-5000	62	14.3
	5001-7000	117	26.9
	7001-10000	161	37.0
	≥10000	90	20.7
Industry type	Hotels	215	49.4
	Restaurants	116	26.7
	Tourist destination/travel agency	86	19.8
	Other hospitality-related business	18	4.1

Table 3 Fornell–Larcker Criterion

Variable	1	2	3	4	5	6	**α**	**CR**	**AVE**
1.Robot social presence	**0.938**	*0.756*	*0.589*	*0.606*	*0.273*	*0.658*	0.93	0.96	0.88
2.Workplace loneliness	-0.614	**0.749**	*0.660*	*0.738*	*0.250*	*0.801*	0.95	0.95	0.56
3.Employee-robot rapport	0.541	-0.615	**0.916**	*0.509*	*0.405*	*0.605*	0.90	0.94	0.84
4.Interpersonal closeness	0.562	-0.696	0.469	**0.798**	*0.226*	0.681	0.90	0.92	0.64
5.Need for human interaction	-0.344	0.334	-0.457	-0.186	**0.699**	0.274	0.77	0.78	0.49
6.Positive emotions*	0.595	-0.630	0.537	0.603	-0.352	**0.800**	0.86	0.90	0.64

Note: The bold numbers in the diagonal row are square roots of the average variance extracted (AVE) value. The lower left triangle area represents correlation coefficients, while the upper right triangle area with diagonal lines in italics indicates HTMT values. * is the control variable.

Table 4 The predictive and explanatory power

Indexes	Variables	Workplace loneliness	Employee-robot rapport	Interpersonal closeness
R^2		0.721	0.376	0.316
Q^2		0.397	0.312	0.196
f^2	Robot social presence	0.162	0.268	0.411
	Employee-robot rapport	0.062		
	Interpersonal closeness	0.148		
	Need for human interaction		0.134	0.001
	Positive emotions*	0.168		

Note: * is the control variable.

Table 5 Path analysis results

Hypothesis: Path	*β*	*SE*	*t*-value	*p*-value	Result
H1: Robot social presence→Workplace loneliness	-0.285	0.051	5.580	0.000	Supported
H2a: Robot social presence→Employee-robot rapport	0.491	0.047	10.497	0.000	Supported
H2b: Employee-robot rapport→Workplace loneliness	-0.161	0.044	3.685	0.000	Supported
H3a: Robot social presence→Interpersonal closeness	0.517	0.057	8.994	0.000	Supported
H3b: Interpersonal closeness→Workplace loneliness	-0.274	0.081	3.395	0.001	Supported
H4a: Need for human interaction * Robot social presence→Employee-robot rapport	-0.189	0.075	2.521	0.012	Supported
H5a: Need for human interaction * Robot social presence→Employee-robot rapport	0.161	0.057	2.837	0.005	Supported
Need for human interaction→Employee-robot rapport	-0.268	0.056	4.819	0.000	-
Need for human interaction→Interpersonal closeness	-0.025	0.069	0.369	0.712	-
Control of demographic variables					
Positive emotions→Workplace loneliness	-0.303	0.056	5.368	0.000	-
Daily robot contact frequency→Workplace loneliness	0.001	0.030	0.020	0.984	-
Gender→Workplace loneliness	-0.002	0.026	0.072	0.943	-
Age→Workplace loneliness	-0.034	0.039	0.868	0.385	-
Education → Recovery work engagement	0.057	0.034	1.711	0.087	-
Position → Recovery work engagement	0.019	0.035	0.541	0.589	-
Work experience → Recovery work engagement	-0.023	0.043	0.528	0.598	-
Income → Recovery work engagement	-0.001	0.039	0.025	0.980	-
Industry → Recovery work engagement	0.016	0.027	0.600	0.548	-

Table 6 Bootstrapping test results of moderated mediation effects

Moderated variable	Mediated variable	Moderated level	Indirect effect	Bootstrap SE	Bootstrap 95% CI
Need for human interaction	Employee-robot rapport	Low: -1SD (-1)	-0.078	0.024	[-0.1395, -0.0382]
		High:+1SD (+1)	-0.025	0.018	[-0.0752, -0.0018]
	Interpersonal closeness	Low: -1SD (-1)	-0.028	0.035	[-0.1200, 0.0167]
		High:+1SD (+1)	-0.097	0.028	[-0.1639, -0.0539]