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The fluency of human-robot collaboration based on human-robot fit

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ABSTRACT

As an important working mode of current manufacturing enterprises, human-robot collaboration (HRC) is of great significance for enterprises to improve production efficiency and quality. However, unfortunately, there are still some problems in the practice of HRC, such as lack of fluency and low quality of HRC, which limit the positive role of HRC in manufacturing enterprises. Therefore, it is of great significance to study and reveal the influencing factors and formation mechanism of HRC fluency for further exerting the positive role of HRC and managing HRC in a targeted way. Building upon a review and analysis of existing literature, this study innovatively explores the formation process of human-robot collaboration fluence based on the theory of person-environment fit.

KEYWORDS

Person-environment fit theory; HRC fluency; Human-robot fit

1. INTRODUCTION

With the transformation and breakthrough of artificial intelligence technology, robots have left the laboratory and factory settings and entered into more complex human work and living environments, gradually developing stronger adaptability and flexibility in these environments. The rapid growth in demand for robot applications in homes and workspaces has promoted the development of some well-performing robots, ranging from mechanical arms to fully humanoid robots, which are expected to assist people in completing various tasks (Ajoudani et al., 2018). However, not all tasks can be solely accomplished by robots; some tasks require human collaboration to be carried out safely, successfully, and efficiently. The ability of humans to solve unexpected problems, think flexibly, and operate with agility plays an important role in eliminating uncertainties and maintaining the stability of robot systems. This also implies that the relationship and roles between humans and robots will be redefined, transforming intelligent robots from auxiliary roles to powerful competitors with the same dominant capabilities as human employees. As an important working model in today's manufacturing industry, human-robot collaboration is of great significance for enterprises to improve production efficiency and quality (Jin et al., 2018), gradually becoming a common way of working. However, unfortunately, issues such as insufficient fluence in human-robot collaboration and low quality of such collaborations still exist in practice (Hoffman et al., 2019), limiting the positive impact of human-robot collaboration in manufacturing enterprises. In recent years, research on the fluence of human-robot collaboration has attracted significant attention. To ensure effective joint activities between robots and humans in complex tasks, continuous smooth interaction between humans and robots is essential, highlighting the importance of further studying the influencing factors of human-robot collaborative fluence.

As can be inferred from the above, the existing empirical research on the influencing factors of human-robot collaboration fluence either approaches from the perspective of employees or from the perspective of robots. However, these single perspectives have limitations in terms of explanatory power regarding the influencing factors of fluence in human-robot collaboration. Charalambous et al. (2015) also suggest that considering both employee and robot factors can better facilitate human-robot collaboration. Therefore, in line with the theoretical viewpoint of the person-environment fit theory, which emphasizes that both internal person factors and external environmental factors jointly affect person behavior (Lewin, 1951), this paper explores the fluence of human-robot collaboration from the perspective of the fit between employees and robots.

2. RELEVANT FOUNDATIONAL THEORIES

2.1. Person-Environment Fit Theory

2.1.1. Basic viewpoints and development of theories

The Person-Environment fit (P-E fit) is usually defined as the compatibility between persons and their environment (Van, 2018), examining the combined impact of person and environmental factors on outcomes, and predicting outcomes based on the fit between person and environmental characteristics. The core premise of the Person-Environment fit theory is that when persons and the environment are compatible, their attitudes and behaviors will be more positive, such as employee emotions, job satisfaction, cross-cultural adaptation of immigrants, retention choices, community commitment, sports and health, etc.; conversely, misfit between persons and the environment can lead to maladaptive attitudes and behaviors (Pee et al., 2017). In this theory, Edwards et al. (1998) divided persons into objective persons and subjective persons, and environments into objective environments and subjective environments. Objective persons refer to the actual attributes of existing persons, while subjective persons refer to persons' perceptions of their own attributes (i.e., self-identity or self-concept); similarly, objective environments include physical and social contexts and events that exist independently of persons' perceptions, while subjective environments refer to the contexts and events perceived by persons. Currently, the Person-Environment fit theory emphasizes that subjective person-environment fit is a key way to positively influence behavior and attitudes; person characteristics include physiological or psychological needs, values, goals, abilities or personalities, education, expectations, etc., while environmental characteristics refer to external rewards, needs, cultural values, environmental resources, tasks, opportunities, etc.

The theory of Person-Environment fit originated from Parsons' (1909) theory of person-job fit. Parsons believed that the key to career choice lies in the fit between person and job characteristics, which can be divided into two aspects: "jobs satisfying people's needs" and "people meeting the requirements of jobs". Building upon Parsons' work, Holland (1959) proposed the theory of personality-occupation fit, categorizing personality into six types including "Realistic", "Investigative", "Artistic", "Social", "Enterprising", and "Conventional". He argued that interests are the driving force of person behavior, and when persons have interests that fit a certain type of occupation, their enthusiasm in that occupation will be significantly higher than in other occupations. Schneider (1987) introduced the "Attraction-Selection-Attrition" model (A-S-A) to explain the mechanism of interaction between persons and the environment, marking a significant advancement in the study of Person-Environment fit theory. This model indicates that when persons share similar or close values with an organization, they will be attracted to the organization, and through the processes of organizational selection and self-selection, they will enter the organization, with the decision to stay in the organization ultimately determined through the process of organizational socialization. Subsequently, many scholars have studied human behavior under the interaction of persons and the environment from different perspectives, enriching the person-environment fit model.

Kristof et al. (1996) integrated previous research and proposed a two-dimensional model that divides person-environment fit into "congruence fit" and "supplementary fit". Congruence fit refers to the degree of alignment between person traits such as values and organizational values. Supplementary fit refers to the degree to which persons and organizations satisfy each other's needs. Building upon this, Cable (2002) further subdivided person-environment fit into congruence fit, demands-abilities fit, and needs-supplies fit. Jansen et al. (2006) argued that person-environment fit is a comprehensive structure composed of occupations, organizations, groups, jobs, and other persons, with the overall person-environment fit being the algebraic fusion of various dimensions. The overall person-environment fit should be equal to the sum of the fiting degrees of each dimension multiplied by the weight each dimension holds, represented as: P-E fit = S1 ⱣV (Person-Vocation fit) + S2 ⱣJ (Person-Job fit) + S3 ⱣO (Person-Organization fit) + S4 ⱣG (Person-Group fit) + S5 ⱣP (Person-Person fit). Beasley et al. (2012) experimentally demonstrated and summarized a generalized model of person-environment fit, known as the General Environment Fit Scale (GEFS). This model suggests that supplementary fit can be further subdivided into environment needs and personal abilities fit (ability fit), personal needs and environmental supplies fit (need fit), and personal unique contributions to the environment (unique role); while congruence fit can be further subdivided into five dimensions: interpersonal similarity of persons to others in the environment (interpersonal similarity) and consistency of values and goals between persons and the environment (value congruence). The impact of these five dimensions on overall fit is determined by the significance of each dimension.

Currently, the theory of Person-Environment fit is widely applied and developed in the fields of health and stress, job adjustment, career choice, person behavioral intentions in virtual communities, and organizational culture. Scholars in the field of human-robot collaboration also suggest applying the theory of Person-Environment fit to explain the psychological behavioral changes of employees in human-robot interaction (Wang et al., 2022). Therefore, this paper is based on the theory of Person-Environment fit to systematically analyze the driving factors and formation mechanisms of the fluency of human-robot collaboration.

2.1.2. Application of Theory

French et al. (1982) first applied the theory of person-environment fit to explain workplace stress, pointing out that stress is not caused unilaterally by persons or the environment, but rather determined by the degree of fit between the person and the environment. Subsequently, with the continuous development of the person-environment fit theory, it has been widely applied in many fields, and scholars have conducted a large amount of theoretical research in organizational behavior. Currently, the person-environment fit theory has been widely applied and developed in the areas of affective commitment, work-family relationships, career choices, person behavioral intentions in virtual communities, and organizational attractiveness. Pee et al. (2017) demonstrated, using employees as subjects, that emotional commitment of employees is higher in cases of person-environment fit compared to cases of misfit. Shen et al. (2018) conducted research in the context of virtual brand communities, showing that person-environment fit has a positive impact on community commitment. Ma Li et al. (2011) believed that the fit between persons and organizations in work-family boundary management styles is beneficial for the mutual promotion of persons' work and family, while misfit can lead to work-family conflicts. Ket Kaew et al. (2020) found through their research that the degree of fit between persons and the environment can significantly reduce persons' turnover intentions. Oh et al. (2014) revealed, through cross-cultural studies, a significant positive correlation between person-environment fit and work attitudes (organizational commitment, job satisfaction, and turnover intention), as well as job performance. Schein et al. (1988) demonstrated a significant relationship between person-environment fit and organizational attractiveness. Hult (2005) conducted a survey on employees' evaluations of the workplace (person-environment fit) in six Western countries, highlighting the strong connection between the work environment and organizational commitment at the person and group levels.

2.2. Research Status of Human-Robot Collaboration Fluency

2.2.1. Definition of Human-Robot Collaboration Fluency

Similar to interactions between people, when persons collaborate in common activities and become accustomed to each other and the tasks, they can achieve a high level of coordination in their actions, with precise and efficient timing, dynamically changing their plans and actions without the need for verbal communication. Hoffman (2019) refers to this high level of coordination and adaptation as the fluency of shared activities. Paliga et al. (2021) define human-robot collaboration fluency as the high coordination between humans and robots, forming a synchronized collaborative team, adapting to each other, and completing tasks together. Human-robot collaboration fluency reflects the quality of collaboration in the work system involving humans, robots, and human-robot teams. Based on the above research, human-robot collaboration fluency emphasizes the high coordination and adaptation of human and robot behaviors in collaborative tasks, effectively reflecting the quality of human-robot collaboration.

2.2.2. Factors Influencing Human-Robot Collaboration Fluency

Due to the preliminary nature and interdisciplinary characteristics of research, scholars' understanding of human-robot collaboration fluency is still in its early stages. Currently, there are few studies on the influencing factors and formation mechanisms of human-robot collaboration fluency. The limited research has analyzed the impact of factors such as the clarity of robot action intentions (Dragan et al., 2015; Psarakis et al., 2022) from the robot's perspective, employees' perception of occupational safety (Kopp et al., 2021), and employees' trust in robots (Paliga et al., 2021) on human-robot collaboration fluency. Starting from the perspective of the robot's impact on human-robot collaboration fluency: Dragan et al. (2015) proposed that the clarity of robot action intentions affects the fluency of human-robot interaction. Clear expression of robot intentions in motion can lead to smoother cooperation between humans and robots compared to motion that meets human expectations. Starting from the perspective of employees' impact on human-robot collaboration fluency: Human-robot interaction safety has always been a focus of scholars' attention. Kopp et al. (2021) believe that if employees doubt the safety of working with robots, they will refuse to work with robots, and employees' perceived occupational safety will affect the fluency of their interaction with robots. Paliga et al. (2021) believe that human-centric human-robot collaboration fluency reflects the cognitive and emotional states that people experience when using robots, describing this cognitive-emotional state as a sense of trust in robots.

3. HUMAN-ROBOT FIT

3.1. Person-Environment Fit in Human-Robot Collaboration

The theory of person-environment fit emphasizes that an person's attitudes and behavioral outcomes are determined by the fiting of person characteristics with the external environment, and a good fit between persons and the environment can lead to positive outcomes (Kristof-Brown et al., 2005). Scholars in the field of human-robot collaboration suggest applying the theory of person-environment fit to explain the psychological behavioral changes of employees in human-robot interactions (Wang et al., 2022). Therefore, based on the theory of person-environment fit, this paper systematically analyzes the driving factors and formation mechanisms of human-robot collaboration fluency.

According to the theory of person-environment fit, when the external environment can provide persons with the resources they expect, or when persons' expectations are in harmony with the external environment, a fiting state is achieved (Kristof-Brown et al., 2005). In addition, Li et al. (2021) suggest that defining the fit between persons and the environment as "compatibility" can more comprehensively reflect the characteristics of the fit. Currently, scholars mainly focus on exploring the impact of human-robot fiting. For example, scholars have found that human-robot fiting not only promotes human-robot interaction (Park et al., 2020) but also enhances productivity and safety (Zhang et al., 2023).

In engineering psychology, human-robot fiting is defined as the degree of suitability between persons and robots in terms of structural and functional characteristics within a human-robot system. However, in organizational behavior, there are no scholars directly explaining human-robot fiting. Schneider et al. (2021) suggest that in human-led human-robot systems, the fiting state between people's expectations and robot behaviors is more prominent. Therefore, based on the theory of person-environment fit, this paper defines human-robot fit as the perceived compatibility between employees' expectations and the resources that robots can provide. Currently, there are few studies on the antecedents of human-robot fiting, with the limited research focusing on robots, confirming that robot adaptability is beneficial for promoting human-robot fiting (Schneider et al., 2021).

3.2. The Fluency Of Human-Robot Collaboration Based On Human-Robot Fit

The theory of person-environment fit suggests that more positive outcomes can be generated when person factors fit environmental factors (Kristof-Brown et al., 2005). Therefore, this paper posits that the fit between employees and robots can positively predict the fluency of human-robot collaboration. On the one hand, person-environment fit has a significant positive impact on employees' work focus and job satisfaction (Lauver, 2001), effectively enhancing emotional interaction between employees and the environment (Lu et al., 2021), increasing employees' satisfaction with the environment (Ho & Pollack, 2014), and promoting positive work outcomes (Ho et al., 2018). For human-robot collaboration, a higher degree of human-robot fit indicates that employees are more satisfied with the interaction and collaboration with robots in their work, enabling employees to invest more attentively in human-robot collaboration work (Ket Kaew et al., 2020), continuously ponder potential issues, reflect on their own shortcomings, accept cooperation with robots with a positive attitude, and continuously improve work output and results. Additionally, human-robot fit also implies that employees possess rich professional knowledge and skills, enabling them to complete more creative tasks, thereby enhancing employees' perception of the fluency of human-robot collaboration.

On the other hand, when employees do not fit the environment, they are in, not only will their attachment and satisfaction with the environment decrease, but they will also develop doubts about the effectiveness of the environment in facilitating task completion (Deng et al., 2016; Howard & Rose, 2019), leading to work fatigue. Therefore, when employees do not fit with robots, they will not only reduce their attachment and satisfaction with robots but also harbor doubts and resistance towards robots' competence in performing their job, thereby adversely affecting the fluency of human-robot collaboration.

4. RESEARCH CONCLUSION

The enhancement of employees' willingness to cooperate and work engagement, as well as the reduction of robot-induced anxiety and coordination difficulties, can lead to the formation of mutual understanding and emotional interaction between humans and robots. This will help the interaction between employees and robots to develop in a direction beneficial for collaborative tasks, leading to the establishment of human-robot fitting relationships and enhancing employees' perception of the fluence of human-robot collaboration.

5. RESEARCH SIGNIFICANCE

5.1. Theoretical Significance

This research not only fills the gap in the study of the formation mechanism of human-robot collaboration fluence, but also helps to systematically understand the process of human-robot collaboration fluence formation. It also expands the application scope of person-environment fitting theory, provides a new perspective for the study of human-robot fitting fluence, and further enriches the research literature on the antecedents and consequences of human-robot fitting.

5.2. Practical Significance

The practical significance of enhancing the flexibility of human resource management in enterprises and emphasizing the impact of human-robot interaction fiting is as follows: On one hand, enterprises can consciously set situational assessments of personnel's views and experiences on robot collaboration in the recruitment process to select employees suitable for the development of the enterprise. During the onboarding phase, enterprise trainers can provide new employees with training and guidance on adapting to robot collaboration, offer more opportunities for employees to collaborate with robots, understand the capabilities of robots, enhance familiarity with robots, build confidence in using them, and foster a sense of identification to achieve compatibility between employees and robots. On the other hand, enterprises should clarify the goals and responsibilities of cooperation between employees and robots. As robots are different from human employees and are less likely to take responsibility for collaborative task failures, enterprises need to carefully consider the issue of responsibility for failed collaborative tasks. At the same time, establish a conflict management system between employees and robots to promote friendly human-robot collaboration, maintain a harmonious relationship between humans and robots, and facilitate smooth human-robot collaboration.

6. LIMITATIONS AND FUTURE PROSPECTS

This study also has some limitations: On one hand, the research is based on theoretical studies and would benefit from empirical analysis using more scientifically valid data to test the research conclusions. Future research could select sample data from manufacturing enterprises in China and Western countries to replicate and verify the research conclusions. On the other hand, due to the fact that research on human-robot collaboration in China is still in its early stages, there is a lack of measurement tools for variables related to human-robot collaboration in the domestic context. This has led to the use of measurement tools mostly derived from Western organizational contexts in this study. Future research could focus on the organizational context in China and develop measurement tools related to human-robot collaboration that are suitable for the Chinese cultural background.

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