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Research Article

Evaluation Method for Robot Interfaces Considering Psychological Safety

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Abstract:
Service robots have been implemented across various sectors in recent years to enhance work efficiency. Developing interfaces with an emphasis on usability from a human-centered design perspective is crucial. Numerous evaluation methods have been suggested for robot interfaces, including those focusing on work efficiency and error rate reduction. Although the NASA-TLX safety evaluation method can assess specific indicators in hazardous situations, an evaluation methodology that emphasizes psychological safety is required. In this study, we propose an evaluation approach that considers psychological safety, utilizing a differential two-wheeled robot. Furthermore, we conducted experiments using three different interfaces. The result of empirical experiments elucidated that interfaces characterized by elevated psychological safety engendered a proclivity among participants towards diverse exploratory methodologies and the adoption of venturesome undertakings. Conversely, interfaces marked by diminished psychological safety precipitated impediments for participants, largely attributed to the palpable absence of tactile reinforcement, thereby obfuscating the stimulation of audacious endeavors. Such revelations accentuate the paramountcy of cognizing the nuanced gradations in psychological safety that modulate the propensity for immersion in exigent tasks. Psychological safety pertains to an individual's perception of the consequences of engaging in interpersonal risk-taking. Thus, it is necessary to explore psychological safety assessment models for various interfaces and conduct surveys among study participants to develop a highly accurate model. In the future, we should also consider control models for automobiles and other vehicles.

Keywords: *Psychological safety, Service robots, User interface, Human centered design, Double loop learning, Gamepad controller*

1. Introduction

In recent years, computers have undergone significant miniaturization and have become increasingly powerful. Service robots capable of both remote control and autonomous operation are now functioning across a wide array of fields. The global market for service robots achieved US$6.7 billion in sales by 2021 [1]. The roles of service robots extend from entertainment to heavy lifting and human assistance [2], enabling developers to design various interfaces tailored to different uses. Various studies have focused on the physical safety of service robots in relation to humans [3], emphasizing that service robots should not cause physical harm and should refrain from behaviors that provoke

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anxiety or discomfort in humans. Because service robots have become more prevalent, their evaluation has become more complex, raising serious concerns [4].

The incorporation of service robots is expected to effectively improve productivity. Numerous studies have addressed the benefits of service robots [5]. However, in one study, soldiers expressed reluctance to deploy robots, owing to a lack of trust in their ability to function safely and effectively in hazardous situations [6]. This mistrust can impede the work of service robots [7], indicating that, even if a service robot is safe, human rejection of its functions can negatively affect productivity.

Conventional service robots are held separately from humans in the same space to ensure physical safety. Such robots cannot easily perform tasks when sharing space with humans, because it is impossible to entirely eliminate the associated risks. The NASA-TLX [8] is a popular tool for assessing subjective mental workload; however, it does not include evaluations of psychological safety against risk or assessments of premise situations. Moreover, gamepad controllers are frequently used for various robot operations and vehicle maneuvers. The impact of these changes was explored in a study by Large et al. [9]. Therefore, it is crucial to evaluate the impact on control efficiency when introducing new interfaces, such as gamepad controllers, into shared spaces between service robots and humans. This evaluation should involve modifying the environment and conditions to assess the effects. Thus, this study aims to establish an evaluation methodology for interfaces that considers psychological safety. Notably, psychological safety has been found beneficial for enhancing team and individual learning in the medical and aviation industries [10, 11]. Incorporating psychological safety into the interface enables more challenging operations, subsequently boosting productivity. This study proposes a novel interface metric for robot control that considers psychological safety. Consequently, we can improve interface performance and enable the selection and development of appropriate interfaces that promote proactive control and enhance efficiency, thereby leading to increased productivity.

2. Application of Psychological Safety to Robot Interface Evaluation

2.1 Psychological Safety

Psychological safety has been defined across many disciplines. In the context of work environments and team activity research, psychological safety represents an individual's perception of the consequences of taking interpersonal risks. It refers to beliefs about the way others might respond when one is at risk; for example, when asking questions, proposing new ideas, receiving feedback, or reporting errors [12]. Psychological safety facilitates the resolution of negative attitudes that arise when data contradict one's thinking [13]. However, psychological safety does not entail environmental comfort, nor does it imply the absence of psychological pressure and problems [14]. Fig. 1 shows the relationship between psychological safety and responsibility. Psychological safety can have positive or negative impacts on aspirations. When psychological safety is high, individuals are more likely to venture into the 'Learning Zone,' where they can embrace challenges and strive for high performance, rather than remain within the comfort or anxiety zone. In the Learning Zone, individuals are not afraid of failure and are open to exploring various approaches. This mindset cultivates innovation and creativity and fosters a culture of continuous improvement.

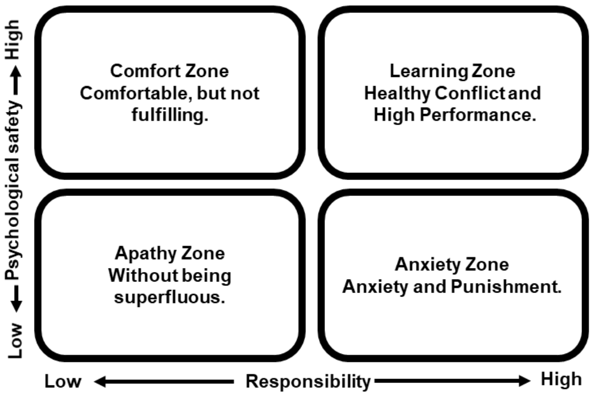


Fig. 1. Four organizational states depend on the balance [15].

This study used seven questions to assess psychological safety as proposed by Edmondson [15]. The following seven-point evaluation questionnaire was used to measure the level of psychological safety provided by the interface. Questions 1, 3, and 5 were formulated to elicit negative responses, whereas questions 2, 4, 6, and 7 generated positive responses. Each response was assigned a score ranging from 1 to 7. More negative responses to this questionnaire correspond to lower psychological safety, whereas more positive responses indicate higher psychological safety.

1. This interface is often the cause of mistakes.
2. This interface encourages the choice of more challenging routes.
3. I was unable to operate this interface as I intended.
4. This interface is ideal for navigating corners.
5. Achieving speed with this interface is challenging.
6. The interface discourages risky maneuvers.
7. The features of the interface assist in the system's operation.

The final psychological safety score (psychological safety score, P) was determined by summing the reversed scores of the positive (Total positive answers, Pa) and negative responses (Total negative answers, Na). The maximum attainable score is 49.

$$P = Pa + (8 - Na) \tag{1}$$

2.2 Interaction Evaluation Methods

Traditional evaluation methods focus primarily on safety and productivity. The system acceptability constructs are shown in Fig. 2 [16]. Elements of practical acceptability include usefulness, cost, compatibility, and reliability. Usability is particularly crucial because it is largely user-dependent. A user-friendly interface minimizes accidents and promotes efficient operation. Consequently, several studies have employed usability testing as an evaluation tool.

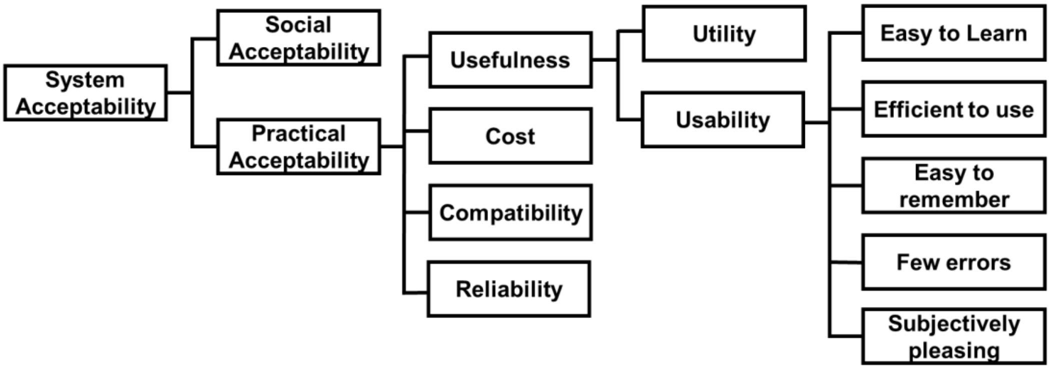


Fig. 2. Composition of system acceptability and usability positioning [16].

The NASA Task Load Index (NASA-TLX) and Situation Awareness Global Assessment Technique (SAGAT) were available for the evaluation of specific indicators. The NASA-TLX is a tool used to evaluate mental workload based on workers' subjective evaluations. The NASA-TLX comprises six categories: mental demand, physical demand, temporal demand, performance, effort, and frustration. Each of these categories was rated on a low, high, and good/poor scale. By contrast, SAGAT is used to assess the ability "to perceive elements in the environment within a specific time and space, comprehend their meaning in the near term, and predict their status in the near future." It is defined as a pilot's visual and kinesthetic perception of environmental elements through an aircraft's display, which provides situational awareness at any given moment. Both the NASA-TLX and SAGAT evaluation methods are safety assessment tools used in hazardous situations. NASA-TLX and SAGAT are essentially problem-solving methods that provide feedback based on work outcomes and thus represent single-loop learning. By contrast, double-loop learning is a success factor that fosters new behaviors and thinking based on new assumptions, values, beliefs, and goals. Single-loop learning is unable to respond to changes in the external environment, whereas double-loop learning can influence mental models and decision-making rules. As shown in Fig. 3, psychological safety assessment enables effective change in the governing variable. Therefore, this study proposes a psychological safety assessment method to enhance productivity in response to risk [17].

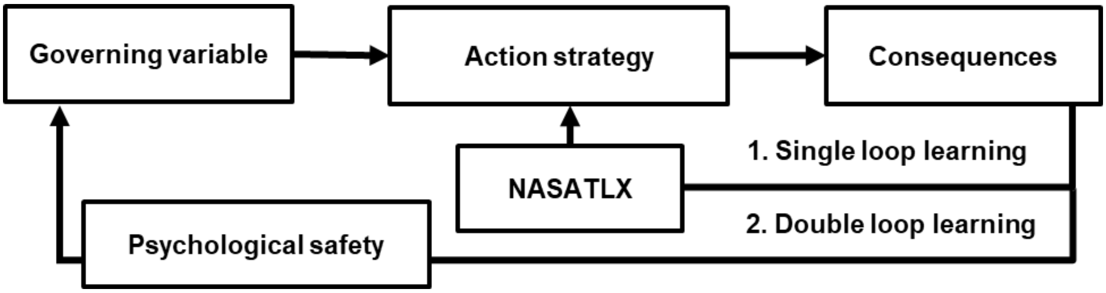


Fig. 3. Double loop learning: effects of psychological safety on robot operation.

3. Robot Control System Configuration

The configuration of the robot control system is illustrated in Fig. 4. This study utilized a differential two-wheeled robot, specifically a Magni Silver model, from Ubiquity Robotics. The fundamental system employs a robotic operating system to manage the robot through an interface. The interfaces tested were a steering wheel controller (THRUSTMASTER T150pro), a gamepad controller (Xbox controller), and a virtual gamepad controller (iPhone8 using Unity). Table 1 lists the types of interfaces and their operations.

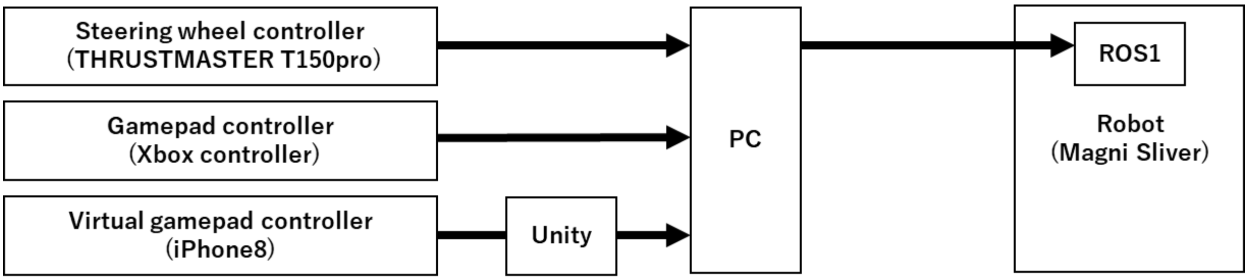


Fig. 4. Robot control system configuration.

Table 1: Types of interfaces and commands to operate them.

Interface	Advanced/Backward command	Turning command
Gamepad controller	Thumbsticks forward /back	Thumbsticks left/right
Virtual gamepad controller	Thumbsticks forward/back	Thumbsticks left/right
Steering wheel controller	Gas pedal/brake	Steering wheel left/right

4. Experiment

The experimental methodology involved testing and evaluating three interfaces–the steering wheel controller, gamepad controller, and virtual gamepad controller–with a focus on psychological safety. Sixteen participants aged 21–24 years participated in the study. They were surveyed regarding their frequency of usage of the three interfaces; the distribution of their responses is listed in Table 2.

Table 2: Frequency of interface use by study participants in the experiment

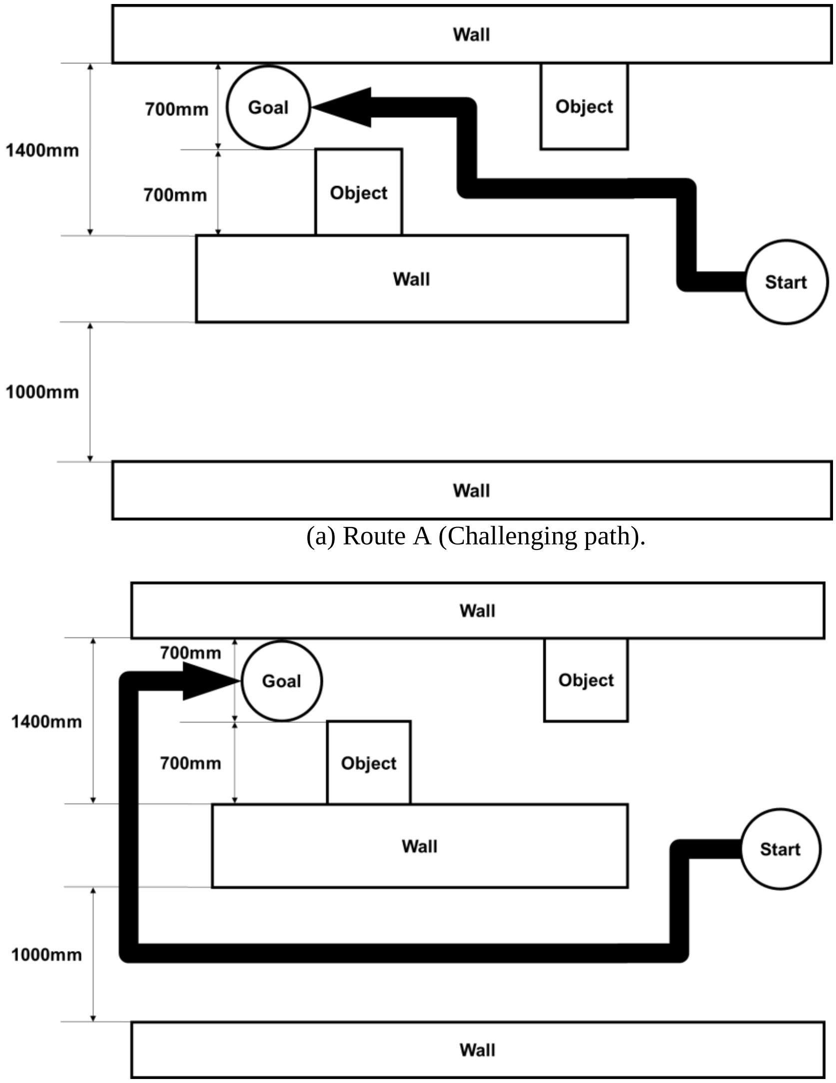
Interface	Nonexistent (never used)	Rarely (once a month or less)	Infrequently (several times a month)	Frequently (at least once a week)
Gamepad controller	6	1	6	3
Virtual gamepad controller	4	5	6	1
Steering wheel controller	1	2	10	3

Figure 5 illustrates the experimental setup. The experiment aimed to identify the differences in psychological safety across various interfaces. The two possible routes, A and B, lead to the following destinations. Table 3 shows Correspondence chart between route and difficulty level.

a) The operation is challenging but the destination is close.
b) The operation is not challenging but the destination is far.

In the event when the robot contacts an object, it restarts from the beginning point, thereby rendering the study participants accountable for the robot's operation. This route may have been altered over the course of the experiment. The experimental procedure was as follows: one interface required approximately 5 min to test, with a total experimental time of approximately 15 min.

1. Explain the interface operation.
2. Participants experience a few minutes of robot operation.
3. Explain the experimental method and conditions.
4. Participants conduct the experiment.
5. Participants answer the psychological safety questionnaire.



(a) Route A (Challenging path).

(b) Route B (Straightforward path).

Fig. 5. Description of the experimental environment and the A and B routes.

Table 3: Correspondence chart between route and difficulty level.

	Navigating towards the goal	Distance to goal
Route A	Challenging path	Short path
Route B	Straightforward path	Long path

5. Experimental Results

Figure 6 shows the results of the psychological safety survey and illustrates the average psychological safety scores of the study participants. The experimental results demonstrated reliability and consistency through the use of the reversed-item questionnaire. Furthermore, by utilizing Equation (1) in Section 2.1, we were able to indicate a high level of psychological safety among the participants. Figure 7 shows the routes chosen by the participants to complete the task. The study initially involved 16 participants; however, owing to uncertain video data acquisition, data from two participants were omitted from the analysis. Based on these findings, the steering wheel controller achieved the highest psychological safety score (39.0 points) among the three interfaces. Moreover, as illustrated in Fig. 7, 11 participants successfully completed the task via Route A. The gamepad controller obtained a psychological safety score (27.8 points). Routes A and B were evenly distributed among the participants, with seven participants choosing each route. Conversely, the virtual gamepad controller obtained the lowest psychological safety score of the three interfaces, scoring only 24.6 points. Figure 7 shows that 11 participants completed the task using the less challenging Route B. The frequency of use questionnaire disclosed that the steering wheel controller received the highest number of "Infrequently" responses compared with the gamepad controller and virtual gamepad controller. To assess the significance of the differences among the three interfaces in this experiment, an analysis of variance (ANOVA) was performed. The results indicate a statistically significant difference among the interfaces.

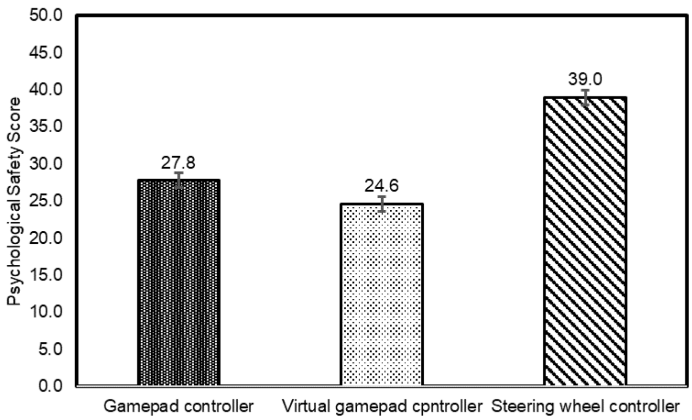


Fig. 6. Results of psychological safety questionnaire.

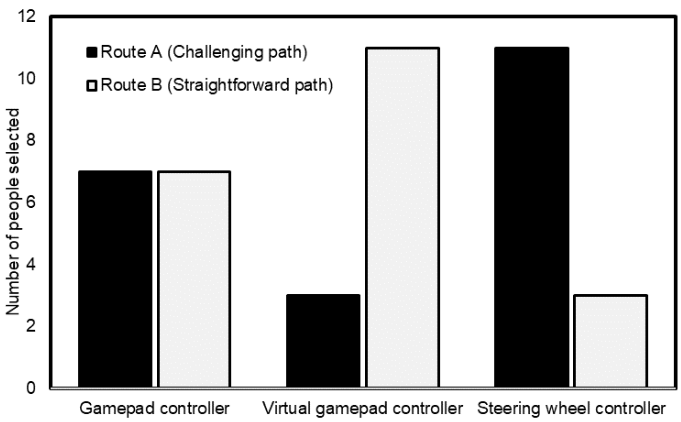


Fig. 7. Results of route selection by hardly.

6. Discussions

The experimental results show significant differences in psychological safety across the three interfaces, as shown in Fig. 6. Furthermore, Fig. 7 underscores the association between higher psychological safety ratings and proactive behavior. With higher levels of psychological safety, individuals are more likely to adopt a forgiving approach to mistakes and failures and actively engage in learning and improvement. Participants also tended to be more open to exploring different approaches and taking risks. For instance, when using the steering wheel controller, participants had fewer encounters with obstacles and exhibited smoother maneuvering. They also displayed courageous behavior in selecting Route A. However, when using the virtual pad controller, they frequently paused to make delicate adjustments, often checking the virtual pad controller in their hands. The lack of mechanical feedback from the virtual pad controller combined with a device controlling both acceleration/braking and steering potentially introduces interference between the two movements [18]. Therefore, participants in the experiment experienced that their maneuvers were not accurately reflected, leading to lower psychological safety and a stronger preference for Route B. Moreover, although participants noted the ease of operating the virtual pad controller when reviewing the controls, the overall result indicated lower psychological safety, which failed to stimulate challenging behavior within the current experimental context. These findings underscore the importance of assessing psychological safety to enable users to effectively utilize an interface beyond considering interface performance or usability alone, irrespective of their skill level. Incorporating psychological safety into the evaluation enables the selection of interfaces that are better suited to the controlled object, considering the specific situation and environment. This approach is expected to enhance control efficiency and productivity.

7. Conclusions

This study introduced a novel evaluation methodology that incorporates psychological safety into interface assessments. Based on the theory of psychological safety, we evaluated three distinct interfaces. The experimental results indicated that the steering wheel controller, which scored highest in psychological safety, prompted more challenging behaviors, such as the selection of difficult routes and smooth maneuvering. Conversely, the virtual gamepad controller, characterized by low psychological safety, elicited passive behaviors, such as the selection of easier routes and frequent stops to confirm maneuvers. Statistically significant differences were observed between the questionnaire scores of the three interfaces. As outlined in Section 2.1, the participants in the experiment were encouraged to engage in challenging behaviors owing to the presence of psychological safety. These findings suggest that varying levels of psychological safety can lead to discrepancies in challenging behaviors. Incorporating psychological safety assessment into our methodology not only enhances the performance of interfaces, but also encourages more proactive control by operators, thereby improving efficiency. This facilitates the selection and development of suitable interfaces that will ultimately boost productivity and safety. However, it is noteworthy that psychological safety represents an individual's perception of the consequences of interpersonal risks. Therefore, exploring psychological safety assessment models for various interfaces and conducting surveys with diverse groups of study participants are necessary to create a more accurate model. The control models for automobiles and other vehicles, including differential two-wheeled service robots, should be scrutinized. Additionally, further subdivision and examination of critical factors related to perceptual and psychological safety are required.

Nomenclature

P	Psychological safety score
Pa	Total positive answers
Na	Total negative answers

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