Behaviors of robot dogs for minimizing construction workers' attentional distraction

Heejae Ahn[1], Qipei Mei[1], Francis Baek[2], Yeseul Kim[3], and Gaang Lee[1]

[1]Department of Civil Environmental Engineering, University of Alberta, Canada
[2]School of Civil and Environmental Engineering, Georgia Institute of Technology, USA
[3]Department of Construction Management, Colorado State University, USA
heejae2@ualberta.ca, qipei.mei@ualberta.ca, francis.baek@ce.gatech.edu, yeseul.kim@colostate.edu, gaang@ualberta.ca

Abstract –

To address limitations of traditional manual patrols on construction sites, such as inconsistent and inaccurate hazard identification, unmanned mobile robots can be deployed. However, specific behavioral parameters of unmanned mobile robots may distract workers' attention. Although related research has been conducted, it remains a critical knowledge gap which robot dogs' behavioral parameters affect human attentional distraction and how they do so. To address this knowledge gap, this study aims to reveal which robot dogs' behavioral parameters affect human attentional distraction and how these parameters influence it by conducting an experiment. As a result, it was analyzed that (1) the robot dog caused the lowest attentional distraction at moderate speeds (1.25 – 1.75 m/s), (2) stop or gaze behaviors tended to increase attentional distraction, and (3) this effect was particularly pronounced under the linear path condition. These findings can contribute to reducing workers' attentional distraction, thereby enhancing safety and improving on-site productivity.

Keywords –

HRC, robot dogs, attentional distraction, eye trackers, fixation

1 Introduction

Due to the complex and dynamic nature of construction sites—where labor, tasks, materials and equipment continuously change across the large space—it is difficult to maintain proactive safety management using static plans alone. Therefore, continuous on-site patrol is necessary to identify emerging risks, verify compliance, and support real-time safety-related decision making [1]. In this paper, the on-site patrol refers to the repetitive routine movement of agent (e.g., personnel or robots) across the site for safety monitoring and maintaining situational awareness.

Conventionally, the on-site patrol tasks have been manually conducted by the safety managers in sites. However, in the conventional on-site patrol method, there can be inevitable oversight because a limited number of safety managers cover the spacious construction sites. Also, there can be variable proficiency among safety managers because they have differences in expertise and safety knowledge. This can lead to subjective judgement in prioritizing the patrol area, resulting in inconsistent and inaccurate hazard identification. To overcome these limitations, unmanned mobile robots have been increasingly highlighted as a promising means to complement the manual on-site patrol [2]. Unmanned mobile robots can substantially widen the patrol coverage, log data in real-time for further analysis for safety management system improvement, and access hazardous areas not approachable by humans.

Despite these advantages, potential concerns arising from emotional and cognitive interactions between human workers and patrolling robots must first be addressed to fully realize their potential. One such concern is workers' attentional distraction resulting from coexisting with robots [3-5]. Particularly in construction field, where various surrounding hazards require workers to properly perceive and respond and individual productivity substantially influences project success, minimizing such attentional distraction is especially critical [6]. Literature demonstrates that how robots behave significantly influences how co-existing workers cognitively and emotionally perceive them [7], which implying the importance of optimizing robots' patrolling behavioral patterns in minimizing workers' distraction.

Although several studies have been conducted regarding the robots' behaviors affecting the human's attentional distraction in construction sites [6, 8], existing studies have mainly focused on drone or proxemics parameter. Given that robot dogs have obviously different appearance and movement mechanisms than drones, which allows us to expect distinct cognitive interaction dynamics. it remains a critical knowledge gap which of robot dogs' behaviors influence human attentional distraction and how they do so. Therefore, this study aims to reveal which behavioral parameters of robot dogs affect human attentional distraction and how these parameters influence it.

2 Research method overview

This study experimentally examines which behavioral parameters of robot dog affect human attentional distraction and how they influence it. To capture attentional processes directly and objectively during human–robot co-presence, eye-tracking was applied to measure gaze allocation and visual attention dynamics in response to robot dog behaviors, providing fine-grained indicators of attentional distraction beyond self-reported measures. The overall procedure of this research is as shown in Figure 1.

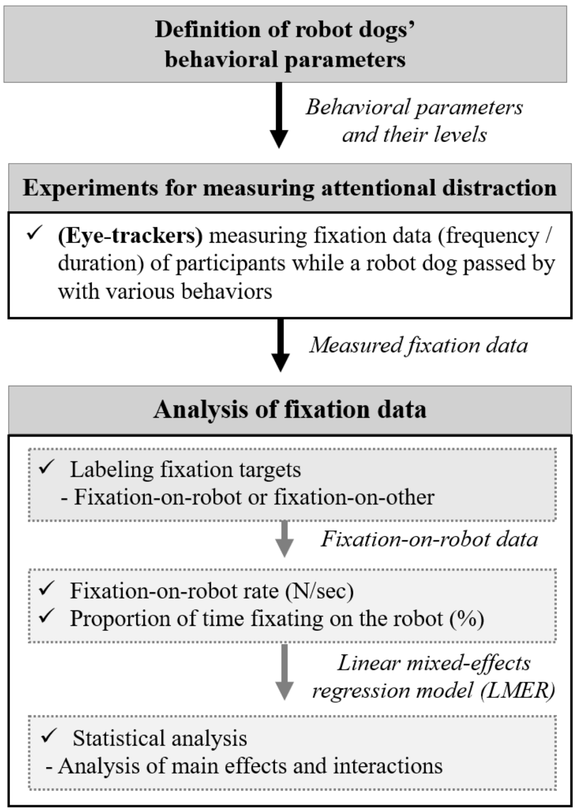


Figure 1. Overall research procedure

First, the robot dogs' behavioral parameters and their levels are defined through comprehensive literature review on human-robot interaction research addressed different robots' behavioral parameters. Next, an experiment is conducted in which participants perform a simple representative construction task while a robot dog passes by them under various combinations of behavioral parameters, and their fixation metrics are measured using eye trackers. The fixation metrics (frequency and duration) are representative metrics when measuring the attentional distraction [5-6]. To analyze fixation metrics, fixations are labeled to be classified as either fixation-on-robot or fixation-on-other. Next, (1) the fixation-on-robot rate (N/s) and (2) the proportion of time fixating on the robot (%) during the robot dog's pass-by are calculated, and these measures are analyzed using a Linear mixed-effects regression model (LMER). Finally, directions for setting robot dogs' behavioral parameters to reduce workers' attentional distraction are proposed.

3 Selection of robot dogs' behavioral parameters

This study covers four robot dogs' behavioral parameters: (1) speed, (2) minimal passing distance, (3) path predictability, and (4) gaze-with-stop. Although other parameters may also be considered, these four were selected based on their practical importance and prior HRC research designs.

3.1 Speed

Existing studies reported robot's speed can affect human comfort which may affect attentional distraction [7, 9]. Therefore, speed was selected as one of the parameters in this study. Wang et al. (2025) [10] classified walking speed into slow walking (0.5–1 m/s), normal walking (1–1.5 m/s), fast walking (1.5–2 m/s), and running (2–2.5 m/s). Referring this classification, Jung et al. (2025) [9] set ground robot speed levels to 1m/s, 1.5m/s, and 2m/s when measuring the effects of ground robots' behavior to human's discomfort.

In this study, the robot dogs' speed parameter was set to the four levels: 0.75 m/s, 1.25 m/s, 1.75 m/s, and 2.25 m/s. These values correspond to the midpoints of Wang et al.'s speed ranges [10], thereby providing representative levels for each speed category.

3.2 Minimal passing distance

In this study, minimal passing distance was defined as the shortest distance between the human's position and the robot dog's moving path at the moment of closest approach as shown in Figure 2.

Minimal passing distance, which is called as proximity in some previous studies, has been adopted as important behavioral parameter in HRC research [11-13]. This is because human may feel the fear of being struck by robots [14]. Xu et al. (2023) [13] revealed that the human maintained distance from the robot dogs about

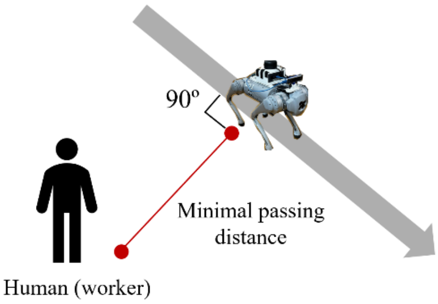


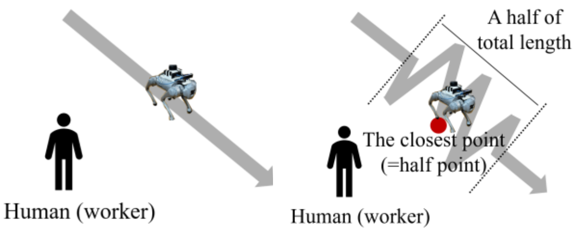
Figure 2. Minimal passing distance

0.7-2.0m when robot dogs pass-by the human. Also, Jung et al. (2025) [9] stated that the psychological implications between 0.45m and 2.0m remain underexplored.

Attentional distraction is closely associated with psychological effects such as perceived safety, discomfort, and stress. Referring these results, in this study, the minimal passing distance parameter was set to the three levels: 0.5 m, 1.25 m, and 2.0 m. Further subdividing minimal passing distance levels would substantially increase the number of behavioral-parameter combinations.

3.3 Path predictability

Unpredictable movements of robots can affect the human's psychological state even when robots maintain objectively safe proximity [14-15]. In this regard, some studies set path predictability as independent variable in HRC research [7, 16]. Since change of psychological state is directly related to the attentional status [16], path predictability was selected as one of the parameters in this study. The path predictability parameter was implemented as a binary factor with two levels: a linear path (predictable) and a zigzag path (unpredictable) (Figure 3-(a), (b)).



(a) Predictable path (linear)   (b) Unpredictable path (zigzag)

Figure 3. Implementation of path predictability

In the zigzag path, the robot dog moved linearly at the start, switched to a zigzag pattern after the first 25 % of the path, and then returned to linear motion after 75 % of the path as shown in Figure 3-(b). The reason for mixing linear and zigzag pattern in zigzag path is to make the robot dog's movement unpredictable. In addition, to make the zigzag path more unpredictable, the lateral deviation in zigzag path (zigzag amplitude) is set as not constant during robot movement.

3.4 Stop and gaze

When robot dogs patrol the construction site, sometimes they can stop to take a photo with equipped cameras. Most commercial robot dogs that come with a camera have it mounted on the head and oriented forward. Therefore, when robot dogs take a photo of workers for some reasons such as personal protective equipment (PPE) violation, they should face the workers. Because robot dogs have a dog-like appearance, workers may feel a gaze from them based on their facing direction, even in the absence of real eyes. Then, a sense of being watched may draw workers' attention to the robot and distract them from the task. Some previous HRC studies have set the gaze of human- or animal-like robot (e.g., humanoid robots or robot dogs) as an independent variable [13, 17].

In this research, to reflect the gaze behavior of patrolling robot dogs in construction sites, the stop and gaze parameter is set to three levels as follows:

- **Non-stop**: it refers to the robot dog moving while facing its heading direction without stopping. In other words, it represents the absence of both gaze and stop, simulating typical robot dog movement.
- **Stop-without-gaze**: it refers to the robot stopping at the point of closest approach to human, that is, at the midpoint of the path in this experiment. The stop duration is 4 s, during which the robot maintains its heading direction. After stop duration is ended, it continues along its path. It simulates a scenario in which a camera is mounted on the side of the robot and images are captured without the robot turning toward the worker.
- **Stop-with-gaze**: the robot stops at the point of closest approach, rotates to face human, and remains stopped for 4 s. After that, it rotates back to its original heading and continues along its path. It simulates a scenario in which camera is mounted on the head of the robot and images are captured after robot turning toward the worker.

Also, each behavioral parameter comprised multiple levels (speed: 4; passing distance: 3; path predictability: 2; gaze-with-stop: 3), resulting in 72 possible behavioral parameter combinations (4×3×2×3), as shown in Figure 4.

4 Experiments

Based on the 72 behavioral parameter combinations (speed: 4; passing distance: 3; path predictability: 2;

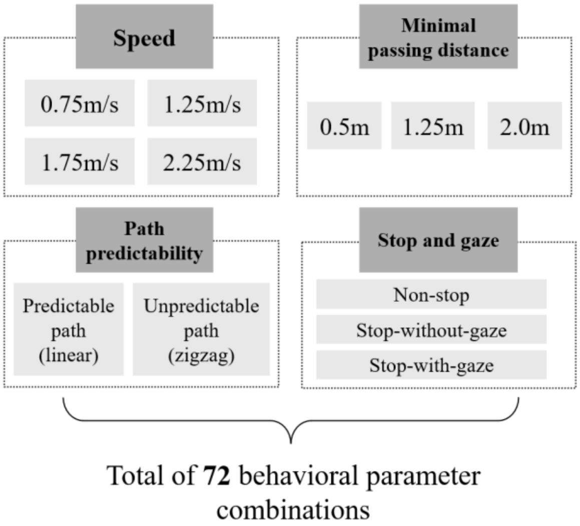


Figure 4. Combinations of behavioral parameter

gaze-with-stop: 3) in Figure 4, an experiment was conducted to measure the participants' attentional distraction while a robot dog passed by them under different behavior combinations. Attentional distraction was assessed by measuring participants' fixation-on-robot rate (N/s) and proportion of time fixating on the robot (%) using eye tracker. An increase in these measures during task indicates greater attentional distraction, as widely assumed in previous HRC studies [5-6]. The experiment was approved by the research ethics board (REB) at University of Alberta (REB ID# Pro00160110). In this experiment, participants' fixation data (frequency and duration), the representative indicators of attentional distraction, were recorded using a Neon eye tracker of Pupil labs (Figure 5-(a)). Also, Go2 robot dog of Unitree was used in this experiment (Figure 5-(b)).

The overall experimental setup is shown in Figure 6. In each trial, the robot dog departed from the start point and reached the end point under a randomly predefined behavioral parameter combination; the distance between the two points was 14 m. While the robot dog was moving in each trial, the participant repeatedly performed a simple bolt fastening task. The participant's location was offset from the midpoint of the robot's path (7 m) by the predefined minimal passing distance in the perpendicular direction.

(a) Neon eye tracker (Pupil labs)　　(b) Go2 robot dog (Unitree)

Figure 5. Eye tracker and robot dog used in the experiment

Background noise can amplify or attenuate the effects of other visual as well as auditory distraction stimuli [18]. To simulate a construction site, construction noise of approximately 87 dB (at the participant position) was played. Also, A video was recorded to mark the robot's start and end times for data cleaning and preprocessing.

Each participant conducted 12 trials so that one participant experienced a total of 12 behavioral parameter combinations. These combinations were assigned in a constrained pseudo-random manner to minimize overlap across participants and avoid overrepresentation of any single factor level. Also, the number of trials was limited to 12 because completing too many trials could lead to habituation to the robot dogs' behavior so that their responses cannot be well caught. In addition, the experimental purpose was partially disclosed to prevent participants from expecting the robot dog's behavioral changes and intentionally regulating their attentional distraction responses.

A total of five participants were recruited (mean age = 29.0 years, SD = 2.9 years; 5 male). Also, the data from two trials were lost due to a recording file corruption, resulting in a total of 58 datasets were analyzed. A priori

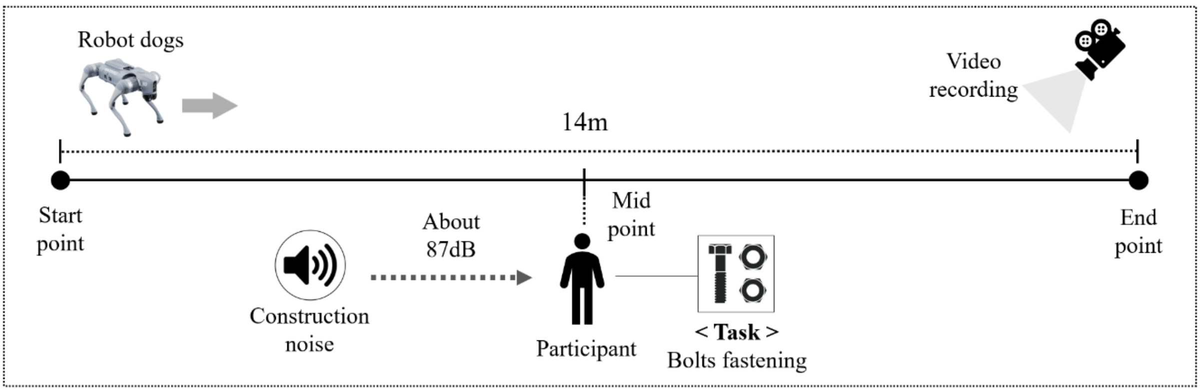


Figure 6. Overall experimental setup

power analysis was not conducted at this pilot study.

4.1 Statistical analyses

4.1.1 Data preprocessing

Collected fixation data were labeled and preprocessed to derive fixation-on-robot frequency (f) and duration (d) during robot movement time (m) for each trial. Then, these values were converted to the fixation-on-robot rate (N/s) and the proportion of time fixating on the robot (%) using Equations (1) and (2). This is because the time required for the robot to traverse 14m differed across the behavioral parameter combinations.

$$Fixation\ on\ robot\ rate\ (N/s) = f/m \quad (1)$$
$$Fixation\ on\ robot\ proportion\ (\%) = d/m \quad (2)$$

4.1.2 Linear mixed-effects regression model

Preprocessed data was analyzed with linear mixed-effects regression model (LMER) to account for individual differences in baseline gaze behavior between participants, the participant was set as random intercept in LMER model.

Among the robot dogs' behavioral parameters, path predictability and stop and gaze parameters were set as categorical variables whereas speed and minimal passing distance parameters were set as continuous variables. Speed parameter was modeled as a continuous variable with a quadratic term because fixation responses were elevated at both the slowest (0.75 m/s) and fastest (2.25 m/s) speeds, suggesting a non-linear (U-shaped) relationship. Therefore, the LMER model can be expressed as Equation (3), where i indexes trials and j indexes participants.

$$y_{ij} = \beta_0 + \beta_1 s_{ij} + \beta_2 {s_{ij}}^2 + \beta_3 d_{ij} + \beta_4 p_{ij} + \beta_5 g_{1,ij} + \beta_6 g_{2,ij} + u_{0j} + \varepsilon_{ij} \quad (3)$$

**s: speed, d: minimal passing distance*
p: path predictability, g: stop and gaze

The fixation-on-robot rate (N/s) and the proportion of time fixating on the robot (%) were transformed to the log and logit scales, respectively, to reflect the distributional properties and bounds of these measures. This LMER-based statistical analysis model was implemented using R software.

5 Results and discussions

5.1 Main effects

5.1.1 Fixation-on-robot rate

The estimated main effect coefficients and their statistical significance are presented in Table 1.

Table 1 Main effect coefficients and statistical significance

Coefficient	Fixation-on-robot rate		Proportion of time fixating on the robot	
	Value	p	Value	p
β_0	-1.215	**0.003***	-2.822	**0.000***
β_1	-0.108	0.405	-0.135	0.459
β_2	0.775	**0.010***	1.146	**0.007***
β_3	-0.124	0.299	0.108	0.514
β_4	0.165	0.258	0.271	0.184
β_5	0.007	0.970	0.444	0.092
β_6	0.177	0.348	0.674	**0.013***

In Table 1, the reference values for the speed and minimal passing distance parameters are the mean speed and the mean passing distance, respectively. In contrast, the reference levels for the path predictability and stop-and-gaze parameters are the linear path and the non-stop condition, respectively.

In the case of fixation-on-robot rate, it was analyzed that coefficient β_0 and β_2 were statistically significant with p-value of 0.003 and 0.010 and 95% confidence intervals (CIs) of [-1.872, -0.558] and [0.192, 1.359], respectively ($p < 0.05$). It was analyzed that exp(β_0) was 0.297, indicating that the predicted fixation-on-robot rate at these reference values is 0.297 N/s. Coefficients β_1 and β_2 represent the shape of quadratic (U-shaped) pattern in speed parameter. Therefore, the significance of β_2 ($p = 0.010$, $p < 0.05$; 95% CI [0.192, 1.359]) indicates that the speed parameter exhibits a significant quadratic (U-shaped) pattern.

When the other parameters are set to reference values, it was analyzed that the fixation-on-robot rate was minimized at 1.55 m/s. However, it can be interpreted as just tendency, given that the speed parameter included only four levels and the sample size was small. Therefore, it may be reasonable to interpret the optimal speed for minimizing the fixation-on-robot rate as lying between 1.25 and 1.75 m/s.

5.1.2 Proportion of time fixating on the robot

As shown in Table 1, it was analyzed that coefficient β_0 and β_2 were statistically significant in the terms of proportion of time fixating on the robot too, with p-value of 0.000 and 0.007 and 95% CIs of [-3.836, -1.804] and [0.332, 1.959], respectively. The proportion of time fixating on the robot in reference parameter levels was predicted as 5.62 %.

Overall, the statistical significance was stronger than that observed for the fixation-on-robot rate. This may be due to individual differences in viewing habits, such as repeatedly glancing at the target of interest or maintaining gaze on it for longer periods.

In particular, the statistical significance of coefficients associated with the stop and gaze parameter (β_5 and β_6) were sharply increased, from 0.970 and 0.348, to 0.092 and 0.013, respectively. This suggests that, although the stop and gaze parameter is likely to influence attentional distraction, individual viewing habits may have introduced variability that obscured its effect on the fixation-on-robot rate.

It was analyzed that coefficient β_6, correlation coefficient between non-stop and stop-with-gaze was statistically significant ($p = 0.013, p < 0.05$; 95% CI [0.148, 1.200]). Also, it was estimated that the proportion of time fixating on the robot increased by 4.83 %p under stop-with-gaze compared with non-stop. Given that the proportion of time fixating on the robot in reference parameter levels was predicted as 5.62 %, this represents a substantial increase.

As a results, the main effect of robot dogs' behavioral parameters can be summarized as below:

- When all of parameters is at reference parameter levels (speed: 1.48 m/s, minimal passing distance: 1.25 m, path predictability: linear path, and stop and gaze: non-stop), the fixation-on-robot rate and proportion of time fixating on the robot was 0.297 N/s and 5.62 %, respectively.
- Because the speed parameter exhibits a significant quadratic (U-shaped) pattern, workers' attention can be distracted more at very slow (0.75 m/s) or very fast (2.25 m/s) speed than moderate speed (1.25 – 1.75 m/s).
- Although participants may differ in viewing habits (e.g., repeatedly glancing vs. maintaining a long gaze), the workers' attention can be more distracted under the stop-with-gaze condition than under the non-stop condition. Moreover, this was a large difference, corresponding to an approximately 1.86 times higher proportion of time spent fixating on the robot.

5.2 Interactions

5.2.1 Fixation-on-robot rate

To examine interaction effects between the parameters, a base LMER was compared with models that included interaction terms. Model improvement was evaluated using the Akaike Information Criterion (AIC) and a likelihood ratio test (LRT). AIC summarizes model quality while accounting for model complexity, and lower values indicate a better model. dAIC represents the change in AIC relative to the base LMER model. The LRT directly compares the base and interaction models; $p < 0.05$ indicates that adding the interaction significantly improves model fit.

As a results of analysis, it was analyzed that two interaction terms (speed $\times$ stop & gaze and path $\times$ stop & gaze) were statistically significant and improved the model (speed $\times$ stop & gaze: dAIC = -1.946 and LRT p-value = 0.041; path predictability $\times$ stop & gaze: dAIC = -2.009 and LRT p-value = 0.050)

Therefore, using two models established with these two interaction terms each, the fixation-on-robot rate (N/s) were predicted as shown in Figure 7.

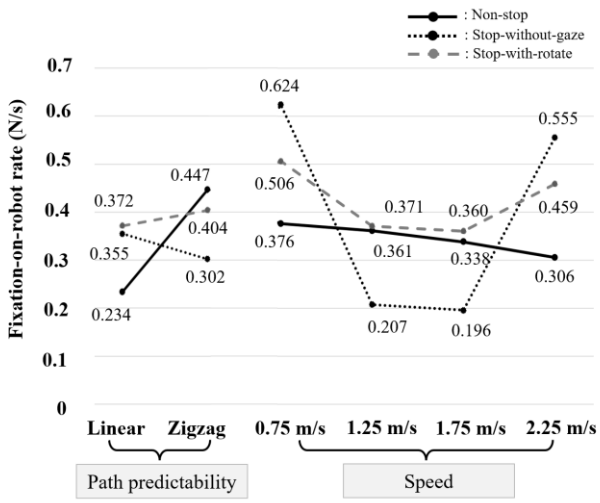


Figure 7. Interaction analysis results
: fixation-on-robot (N/s)

In Figure 7, all parameters other than interaction parameters were held at their reference levels. Under non-stop condition, fixation-on-robot rates showed little variation across speed levels. However, when there were stop or gaze movements, the fixation-on-robot rates were sharply increased especially in speed with 0.75 m/s and 2.25 m/s. This suggests that, compared to when stop- or gaze-related behaviors are present, the effect on attentional distraction is less influenced by speed when such behaviors are absent. This may be because sudden stopping or gazing at very low (0.75 m/s) or high (2.25 m/s) speeds may be perceived as an unusual situation (e.g., hazard or emergency detection) not usual patrolling process by participants.

Under linear path condition, the stop or gaze movements tended to produce a sharp increase in fixation-on-robot rates. In contrast, under the zigzag path condition, the non-stop behavior yielded the highest fixation-on-robot rates (0.447 N/s). This may be because participants did not expect stop- or gaze-related behaviors when the robot followed a linear path, whereas under a zigzag path they may have been more prepared for, or anticipating, such sudden movements.

5.2.2 Proportion of time fixating on the robot

A base LMER was compared with models that included interaction terms in proportion of time fixating on the robot. It was analyzed that only one interaction term was statistically significant and improved the model (path predictability × stop & gaze: dAIC = -5.026 and LRT p-value = 0.011), whereas the speed × stop & gaze interaction was marginally non-significant (LRT p-value = 0.053) which was not the case for fixation-on-robot rate results.

The proportion of time fixating on the robot (%) was predicted using a model established with path predictability × stop interaction term (Figure 8).

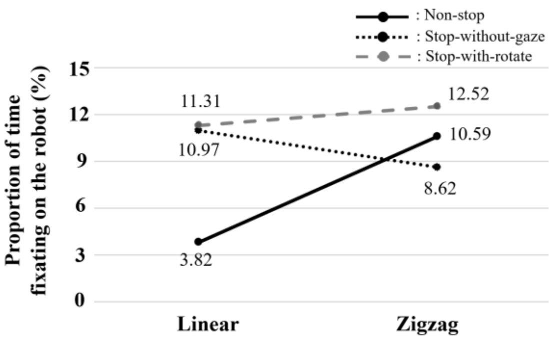


Figure 8. Interaction analysis results
: proportion of time fixating on the robot (%)

In Figure 8, all parameters other than interaction parameters were held at their reference levels. Like the results of fixation-on-robot rates, under linear path condition, the stop or gaze movements tended to produce a sharp increase in the proportion of time fixating on the robot. However, under the zigzag path condition, the stop-with-gaze behavior produced the highest proportion (12.52 %) of time fixating on the robot unlike the fixation-on-robot rate results.

This may be because the continuous and various robot dogs' actions (zigzag movement with stop and rotate) strongly captured attention and interest, causing participants to sustain their gaze on the robot for longer once they looked.

5.2.3 Suggestion for robot dog's behavior settings

As this study was conducted as a pilot, only five participants were recruited, which is a small sample given the large number of robot parameter combinations (72). Despite the data scarcity circumstance, several statistically significant results were observed. Reflecting these results, the directions for setting robot dog behaviors to minimize the workers' attentional distraction were suggested as below:

- Because the effect of speed on attentional distraction followed a U-shaped quadratic pattern, maintaining a moderate speed (approximately 1.25–1.75 m/s) may be preferable. In particular, when the robot's behavior included stopping or gazing (rotating), very slow (0.75 m/s) or very fast (2.25 m/s) speeds were more likely to cause substantial attentional distraction.
- Although it was not statistically significant in fixation-on-robot rate, the robot's stop-with-gaze behavior, such as taking photos or recording the scene, tended to increase attentional distraction. Therefore, mounting the camera on the side of the robot dog may be one practical way to prevent increased attentional distraction among workers.
- If mounting the camera on the side of the robot dog is not feasible, another practical approach to keep attentional distraction low is to avoid including stop or gaze(rotate) behaviors when the robot is moving along a linear path segment.

However, the findings should be interpreted cautiously when extended to real site conditions. For instance, distraction may increase under higher cognitive demands but decrease when attention is directed to other factors, such as co-worker coordination.

6 Conclusion

In this paper, an experiment was conducted to examine how patrolling robot dogs' behaviors affect construction workers' attentional distractions. As a result, three statistically significant findings were identified: (1) the robot dog's speed tended to increase workers' attentional distraction when it was either very slow (0.75 m/s) or very fast (2.25 m/s); (2) the robot dog's stop-with-gaze behavior tended to increase attentional distraction; and (3) stop or gaze (rotation) behaviors tended to increase attentional distraction more on a linear path than on an unpredictable path. In addition, based on these results, the robot dogs' behavior setting directions to minimize workers' attentional distractions were suggested.

The results of this study can help robot dog designers or operators to establish guidelines for designing robot dog or operating it on construction sites. Also, the findings of this research can contribute to reducing construction workers' attentional distraction, thereby enhancing safety and improving on-site productivity.

However, this was a pilot study conducted on only five males and using only a simple bolt-fastening task, so the results should be interpreted as preliminary trends rather than generalizable conclusions. In addition, within-trial fluctuations in attentional distraction were not analyzed, although they may vary with the robot dog's location (e.g., near vs. far). Future studies will therefore include a larger and more diverse sample and analyze within-trial segments based on the robot dog's location.

Acknowledgement

This study was supported by the NSERC Discovery Grants Program (Award No. RGPIN-2025-05214), and the NSERC Alliance Advantage Program (Award No. ALLRP 578484-22).

References

[1] Y. C. Yoon, K. S. Chung, Y. I. Kim, and G. H. Kim. Effect of the application of safety patrol management system (SPMS) upon the reduction of disaster & accident occurrences in construction site. *Journal of the Korea Safety Management & Science*, 16(2):53-61, 2024. doi: https://doi.org/10.12812/ksms.2014.16.2.53.

[2] S. Agrawal, N. Amrutha, B. M. Punyashree, V. Raksha, and D. R. Yuktha. IoT-based patrolling robot for construction sites. In *International Conference on Interdisciplinary Approaches in Civil Engineering for Sustainable Development,* pages 57-69, Bengaluru, India, 2023.

[3] D. Ghiglino, D. De Tommaso, A. W. Lukomski, and A. Wykowska. The presence of a humanoid robot can be detrimental to human performance in an attentional task. *Technology, Mind, and Behavior,* 5(3):146-159, 2024. doi: https://doi.org/10.1037/tmb0000137.

[4] I. Jeelani and M. Gheisari. Safety challenges of UAV integration in construction: conceptual analysis and future research roadmap. *Safety science,* 144:105473, 2021. doi: https://doi.org/10.1016/j.ssci.2021.105473.

[5] G. Albeaino, P. Brophy, I. Jeelani, M. Gheisari, and R. R. Issa. Impact of drone presence on construction individuals working at heights. *Journal of Construction Engineering and Management*, 149(11):04023119, 2023. doi: https://doi.org/10.1061/JCEMD4.COENG-13861.

[6] I. Jeelani and M. Gheisari. Safety challenges of UAV integration in the construction industry: Focusing on workers at height. *University of Florida*, 2022.

[7] J. T. Butler and A. Agah. Psychological effects of behavior patterns of a mobile personal robot. *Autonomous Robots*, 10(2):185-202, 2001.

[8] G. Albeaino, I. Jeelani, M. Gheisari, and R. R. Issa. Assessing proxemics impact on human-robot collaboration safety in construction: A virtual reality study with four-legged robots. *Safety Science*, 181:106682, 2025. doi: https://doi.org/10.1016/j.ssci.2024.106682.

[9] S. Jung, H. C. Kim, H. Kang, and Y. G. Ji. Proxemic discomfort in shared spaces: The role of mobile robot behavior and pedestrian state. *International Journal of Human–Computer Interaction*, 1758-1775, 2025. doi: https://doi.org/10.1080/10447318.2025.2526574a.

[10] Z. Wang, J. A. Zhang, H. Zhang, M. Xu, and J. Guo. Passive human tracking with WiFi point clouds. *IEEE Internet of Things Journal*, 12(5):5528–5543, 2024. doi: https://doi.org/10.1109/JIOT.2024.3487193.

[11] R. Bretin, M. Khamis, and E. Cross. “Do I run away?”: Proximity, stress and discomfort in human-drone interaction in real and virtual environments. In *IFIP Conference on Human-Computer Interaction,* pages 525-551, York, UK, 2023.

[12] M. M. Neggers, R. H. Cuijpers, P. A. Ruijten, and W. A. IJsselsteijn. The effect of robot speed on comfortable passing distances. *Frontiers in Robotics and AI*, 9:915972, 2023. doi: https://doi.org/10.3389/frobt.2022.915972.

[13] X. Xu, Z. Meng, E. Li, M. Khamis, P. G. Zhao, and R. Bretin. Understanding dynamic human-robot proxemics in the case of four-legged canine-inspired robots. In *2025 IEEE International Conference on Robotics and Automation (ICRA),* pages 7808-7814, Atlanta, USA, 2025.

[14] S. Nertinger, R. J. Kirschner, S. Abdolshah, A. Naceri, and S. Haddadin. Influence of robot motion and human factors on users' perceived safety in HRI. In *2023 IEEE International Conference on Advanced Robotics and Its Social Impacts (ARSO)* pages, 46-52, Berlin, Germany, 2023.

[15] P. Pandey, R. Parasuraman, and P. Doshi. Integrating perceptions: A human-centered physical safety model for human-robot interaction. In *2025 34th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN),* pages 1823-1830, Eindhoven, Netherlands, 2025. doi: https://doi.org/10.1109/RO-MAN63969.2025.11217747.

[16] M. Koppenborg, P. Nickel, B. Naber, A. Lungfiel, and M. Huelke. Effects of movement speed and predictability in human–robot collaboration. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 27(4):197-209, 2017. doi: https://doi.org/10.1002/hfm.20703.

[17] D. Fu, F. Abawi, and S. Wermter. The robot in the room: influence of robot facial expressions and gaze on human-human-robot collaboration. In *2023 32nd IEEE International Conference on Robot and Human Interactive Communication,* pages 85-91, Busan, Republic of Korea, 2023.

[18] C. A. Salagovic and C. J. Leonard. A nonspatial sound modulates processing of visual distractors in a flanker task. *Attention, Perception, & Psychophysics*, 83(2):800-809, 2021. doi: https://doi.org/10.3758/s13414-020-02161-5.