Taylor & Francis
Taylor & Francis Group

IISE Transactions on Occupational Ergonomics and Human Factors

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/uehf21

Effects of Prior Robot Experience, Speed, and Proximity on Psychosocial Reactions to a Soft Growing Robot

Tahira M. Probst, Rebecca J. Lindgren, Ryan J. Dorosh, Justin C. Allen, Lorraine S. Pascual & Ming Luo

To cite this article: Tahira M. Probst, Rebecca J. Lindgren, Ryan J. Dorosh, Justin C. Allen, Lorraine S. Pascual & Ming Luo (25 Nov 2023): Effects of Prior Robot Experience, Speed, and Proximity on Psychosocial Reactions to a Soft Growing Robot, IISE Transactions on Occupational Ergonomics and Human Factors, DOI: 10.1080/24725838.2023.2284193

To link to this article: https://doi.org/10.1080/24725838.2023.2284193

Published online: 25 Nov 2023.

IISE TRANSACTIONS ON OCCUPATIONAL ERGONOMICS AND HUMAN FACTORS
https://doi.org/10.1080/24725838.2023.2284193

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

Effects of Prior Robot Experience, Speed, and Proximity on Psychosocial Reactions to a Soft Growing Robot

Tahira M. Probst[a], Rebecca J. Lindgren[a], Ryan J. Dorosh[b], Justin C. Allen[b], Lorraine S. Pascual[c] and Ming Luo[b]

[a]Department of Psychology, Washington State University, Vancouver, Washington, USA; [b]School of Mechanical and Materials Engineering, Washington State University, Pullman, Washington, USA; [c]Department of Digital Technology and Culture, Washington State University, Pullman, Washington, USA

OCCUPATIONAL APPLICATIONS

After viewing video vignettes of human interactions with a novel soft growing robot, we found that participants reported fewer perceived safety hazards, less anxiety and fear about robots, reduced social hesitancy about human-robot collaboration (HRC), and lower technology-induced fears of job insecurity. Unlike prior research with traditional rigid manipulators, we found that the manipulated proximity of the human-robot interactions was unrelated to any of these outcomes, suggesting closer interactions may be possible without adverse psychological resistance. On the other hand, fear of robots, perceived hazards, technology-induced job insecurity, and robot anxiety were all significantly lower when human-robot interactions were slower. Interestingly, participants with more extensive prior robot experience displayed preferences for faster HRC interactions. Many occupations are ripe for automation within the next two decades, yet technical and psychological barriers to adoption remain. Our research suggests that novel soft growing flexible robots may be a fruitful area for future advancements.

TECHNICAL ABSTRACT

Background: A growing body of literature exists on the determinants of psychosocial reactions to human-robot collaboration (HRC), including prior experience working with robots, speed of human-robot interactions, and the level of proximity between the human and the robot. However, the results from this emerging literature and implications for occupational settings have largely been based on research involving traditional rigid robots.

Purpose: Advancements in novel soft growing flexible robots necessitate evaluating how and whether such prior research generalizes to this new class of robots.

Methods: By manipulating the speed and proximity of an HRC task, and by measuring psychosocial robot-related attitudes pre- and post-task among research participants ($N = 112$), we evaluated the main and interactive effects of speed, proximity, and prior robot experience on perceived safety hazards, fear of robots, robot anxiety, technology-induced job insecurity, and social hesitancy toward robots.

Results: Following observations of HRC with the novel soft robot, participants perceived fewer safety hazards associated with working with robots, expressed less anxiety and fear about robots, reported less social hesitancy about HRC, and had lower levels of technology-induced fears of job insecurity. Proximity was unrelated to any of these outcomes, whereas fear of robots, perceived hazards, technology-induced job insecurity, and robot anxiety were all significantly lower under slower speed conditions. Finally, participants with more extensive prior robot experience displayed preferences for faster HRC interactions.

Conclusions: Many occupations are ripe for automation, yet technical and psychological barriers to adoption remain. Our findings indicate potential advantages posed by novel soft growing robots relative to traditional rigid robots. Closer interactions without adverse effects on psychosocial reactions may be possible with this newer class of robots. Developing variable speed soft robots, which can be adjusted as user experience grows, may also be useful technical avenue to pursue.

ARTICLE HISTORY
Received 11 May 2023
Accepted 13 November 2023

KEYWORDS
Psychosocial reactions; soft robots; human-robot collaboration

CONTACT Tahira M. Probst probst@wsu.edu Department of Psychology, Washington State University, Vancouver, WA, USA.
This article has been corrected with minor changes. These changes do not impact the academic content of the article.

1. Introduction

Accelerated by the COVID-19 pandemic, the world of work is undergoing momentous change. Nearly half of all occupations (including those in production, transportation, extraction, and agriculture) are ripe for automation within the next two decades (Frey & Osborne, 2017). At the same time, labor shortages within the U.S. have plagued post-pandemic recovery efforts and are particularly dire for jobs in harsh occupational environments with high health and safety risks. As a result, increased incorporation of automation and human-robot collaboration (HRC) has the potential to address some of these challenges associated with the future of work. Yet, adoption of collaborative robots in the workplace has remained low, often due to psychosocial barriers such as lack of trust and fears of technology-induced obsolescence (Görke et al., 2017).

Currently, traditional rigid robots and manipulators dominate in the industrial realms of manufacturing, logistics, and process automation. The inherent design of these technologies is advantageous due to the precision, reliability, and reduced cost over longer working periods (Lasi et al., 2014). However, these rigid robotic platforms must be covered by cages, so are inaccessible to workers during execution, and there are strict safety procedures required to operate these robots (e.g. ISO regulations requiring a minimum distance of 20 inches when operating alongside rigid manipulators). Even with these stringent safety protocols, there have been tragic incidents in recent years involving robotic manipulators, including accidental deaths (Collins, 2015). Yet, with increasing manufacturing complexity. coupled with the needs from emerging areas such as healthcare, warehousing, and other labor-intensive fields, the need for robots that can safely collaborate with humans remains high. As one indication of this need, Amazon has been sponsoring an annual Amazon Picking Challenge since 2015, because picking and placing tasks with thousands of different objects in their warehouses continue to be executed by employees instead of commercial manipulators (Corbato et al., 2018).

Unfortunately, while there is clear demand for collaborative robots, technical and psychosocial barriers to such HRC remain (Dzedzickis et al. 2021). Indeed, in their recent call for research at the intersection of technology and worker well-being, NIOSH scientists acknowledged that new technologies, such as robots and autonomous systems, can dramatically increase productivity yet may also risk exacerbating work-related stressors and psychological distress (Felknor et al., 2022). Moreover, higher levels of job-related stress can induce cognitive failures, which in turn can lead to higher rates of injuries and accidents at work (Bridger et al., 2010; Linden et al., 2005; Petitta et al., 2019). An increased prevalence of robots has also been associated with greater perceptions of job insecurity, an increased risk of burnout, and a greater enactment of workplace incivility (Yam et al., 2023).

While much of the extant literature on HRC in industrial settings involves traditional rigid manipulators, recent advancements over the past decade (see Rus & Tolley, 2015 for a review) have been made in the development of Next Generation (NextGen) *soft robots* (see Figure 1). Such robots are composed of flexible or stretchable materials and have the potential for greater inherent safety, superior reach and accessibility, and lower capital and operating costs (Negrello et al., 2019; Xing et al., 2020). Not surprisingly, the demand for these next generation robots is expected to grow exponentially in the coming years, with market valuation expected to increase from just over $1 billion in 2020 to more than $6 billion by 2026 (Mordor Intelligence, 2021). To date, most soft roboticists have focused their efforts primarily on sensing, control, and planning technologies in the absence of user input (i.e. without gauging the experience of the users who will eventually operate the soft robots). Thus, while novel soft robots have the potential to more safely, inexpensively, and effectively interact with humans in high complexity environments, there has been no empirical assessment, to our knowledge, of the extent to which humans may be resistant to working alongside soft robots, nor the psychosocial

Figure 1. An example of a novel soft growing robot.

correlates of such resistance. Moreover, because these soft, flexible, growing robots have not yet achieved widespread use, few have had the opportunity to interact with such robots or observe others doing so.

Therefore, the purpose of our research was three-fold. First, we investigated the extent to which exposure to soft robotic technology, *via* an observation of a HRC task, will be associated with less adoption hesitancy, perceived safety hazards, fear, anxiety, and technology-induced job insecurity following the task observation. Second, because previous research with rigid robots has demonstrated the relevance of speed and proximity in HRC, we experimentally manipulated these two factors to determine whether attitudes toward HRC with a soft robot vary as a function of slow vs. fast and near (i.e. collaborative) vs. far (i.e. cooperative) HRC interactions. Third, because individuals vary in the extent to which they have had prior experience interacting with robots and autonomous systems, we also evaluated the extent to which prior robot-related experiences moderate the impact of speed and proximity on psychological attitudes.

Hypothesized Effects of Robot Exposure

Prior research generally suggests that exposure to robots can be beneficial toward breaking down negative attitudes and assumptions about robots. For example, research by Pérez et al. (2020) involving rigid manipulators found that psychological attitudes toward and acceptance of HRC were influenced by prior experience working with robots, with experts generally reporting greater confidence and more positive attitudes compared to novices. Similar findings were reported by Müller-Abdelrazeq et al. (2019), such that research participants with greater prior robot-related experience reported fewer negative attitudes toward robots. In the latter study, HRC attitudes also improved from initial baseline levels, with participants indicating increased positive attitudes and decreased technology-related job insecurity following an experimental interaction with a robot. While these earlier studies were conducted with rigid manipulators, we similarly expect that exposure to the soft growing robot *via* the video vignette will result in more positive attitudes post-observation compared to baseline. Thus, we hypothesized:

> *Hypothesis 1:* Attitudes toward HRC will improve from pre- to post-task, such that perceived safety hazards, fear, anxiety, job insecurity, and social hesitancy will decline over time, whereas rated robot warmth will increase.

Potential Effects of Proximity

According to Schmidtler et al. (2015), human-robot interactions can range from: (a) mere *coexistence* involving limited temporal and spatial overlap; to (b) *cooperation*, involving completion of a shared task *via* strict division of labor' and (c) *collaboration*, where human operators and robots are in direct contact and exchange forces to complete an assigned task. With those latter two classifications in mind, our study manipulated the proximity of human-soft robot interactions to compare psychosocial reactions between *cooperation* during a shared task (i.e. low proximity) and actual *collaboration* involving direct contact (i.e. high proximity).

As noted earlier, human interactions with rigid robots are strictly controlled due to the potential for high energy contact and work-related injuries and fatalities. Perhaps not surprisingly, prior research has found that perceived trust ratings (MacArthur et al., 2017), as well as comfort, likeability, and task completion time (Kim & Mutlu, 2014) were worse when robots and humans interacted more closely. Similarly, Stark et al. (2018) found that participants exhibited a tendency to physically move away from a robot arm when it entered their personal space, indicating a level of physical discomfort. Indeed, Arai et al. (2010) concluded, based on physiological and self-reported measures of stress during interactions with a rigid robot, that a minimum distance of 2 m was needed for optimal HRC.

However, we posit that these generally negative effects may be due to the nature of the rigid manipulators and that the real and perceived harm that can occur when operating in close proximity to such robots. Unlike traditional industrial rigid manipulators, soft flexible growing robots are inherently designed to absorb contact forces, thus potentially mitigating these psychosocial concerns. Moreover, research on the development of humanoid robots for human comfort (e.g. to aid children with sensory processing disorders) has found that participants not only preferred robots that were soft, but also considered them to be safer (Block Block & Kuchenbecker, 2019). As a result, whereas psychosocial reactions to close interactions with rigid robots might be more negative than distant interactions, proximity may be less predictive of reactions to interactions with soft robots. Thus, we posed the following research question:

> *Research Question 1:* Will proximity remain a significant predictor of psychological reactions to a soft robot, that is, perceived safety hazards, fear, anxiety,

job insecurity, and social hesitancy, and perceived robot warmth?

Hypothesized Effects of Speed

Research using rigid manipulators has typically found that greater speed in HRC is associated with more negative outcomes, such as increased anxiety (Kulic & Croft, 2005), greater perceived workload (Koppenborg et al., 2017), and more time pressure (Story et al., 2022). MacArthur et al. (2017) found that participants reported greater trust when interacting with robots that approached them slowly compared to robots that were sped up. On the other hand, Story et al. (2022) found that participant frustration was higher when robot speeds were perceived to be too slow. Based on the preponderance of evidence (and despite the fact that the extant literature has only been done with rigid manipulators), we similarly predicted that:

Hypothesis 2: Compared to the slow HRC condition, fast robot speeds will be associated with more negative psychological reactions, namely higher safety hazards, fear, anxiety, job insecurity, and social hesitancy, and lower perceived robot warmth.

Prior Robot Experience as a Moderator

While there is a growing body of literature examining the direct effects of prior experience working with robots on attitudes toward HRC (e.g. De Graaf & Allouch, 2013; Halpern & Katz, 2012; Nomura et al., 2006; 2011; Weiss et al., 2009), we know of no reported research that has examined how such prior experience might moderate the effects of manipulable design features of HRC, such as speed and proximity. Thus, it is unknown whether the hypothesized effects of speed and proximity might be stronger or weaker among individuals who have more vs. less prior experience interacting with robots. As such, we sought to address this gap in the literature. Specifically, and based on prior findings that increased experience is generally associated with more favorable outcomes, we anticipated that individuals with greater prior robot experience will exhibit attenuated effects as a result of the experimentally manipulated design features. In other words, manipulated changes in proximity and speed would have less effect on psychosocial reactions of high prior exposure participants. We hypothesized that:

Hypothesis 3: Prior experience will moderate the effects of proximity (*H3a*) and speed (*H3b*) on psychosocial reactions to the soft robot HRC.

2. Methods

2.1. Participants

Our study (protocol #19929-001) was classified as exempt on 8 March 2023 by the Human Research Protection Program within the Office of Research Assurances at Washington State University. The university's SONA system was used for the recruitment of $N = 122$ participants, as this system allows researchers to post a study to an online platform in which students opt into studies following their informed consent in exchange for credits. Those credits can then be applied toward research participation for course assignments and/or extra credit. Qualification for this study required that the student be at least 18 years old, with a mean participant age of 20.78 ($SD = 3.36$). The gender of the participants was predominantly (79.5%) female. Seventy-three percent of the participants were White; 11.5% were Asian, 7.4% Black or African American, and 15.6% of Hispanic or Latinx ethnicity. Nearly half (47.5%) of respondents indicated they were full-time, non-working students; an additional 41.8% were employed part-time, and 4.9% were employed full-time. A majority (59.8%) indicated they had some level of prior interactions with robots, with 24.6% reporting some degree of experience building a robot, and 48.4% reporting some experience controlling a robot.

2.2. Materials and Experimental Manipulations

Figure 2 provides an overview of the experimental procedure which is described in greater detail below.

The Human-Robot Collaboration Task

A series of four video vignettes (near-slow, near-fast, far-slow, and far-fast) were created to post in the online study so that participants could observe the manipulated human-robot interactions to perform an assigned task. The objective of the task was for the worker to build a pyramid, which required six cubes that the robot delivered to the worker one at a time. The worker then stacked those cubes into a pyramid as they were delivered by the robot. For the cooperative (*low proximity*) conditions, the robot dropped the cube into a box, after which the worker removed the cube from the box to place in the pyramid. For the collaborative (*high proximity*) conditions, the worker took the cube directly from the robot arm then placed the cube in the pyramid. Thus, in the high proximity interaction, there was an actual exchange of forces between the robot and human (Figure 2).

In order to maintain as much consistency as possible across the video vignettes, speed was manipulated

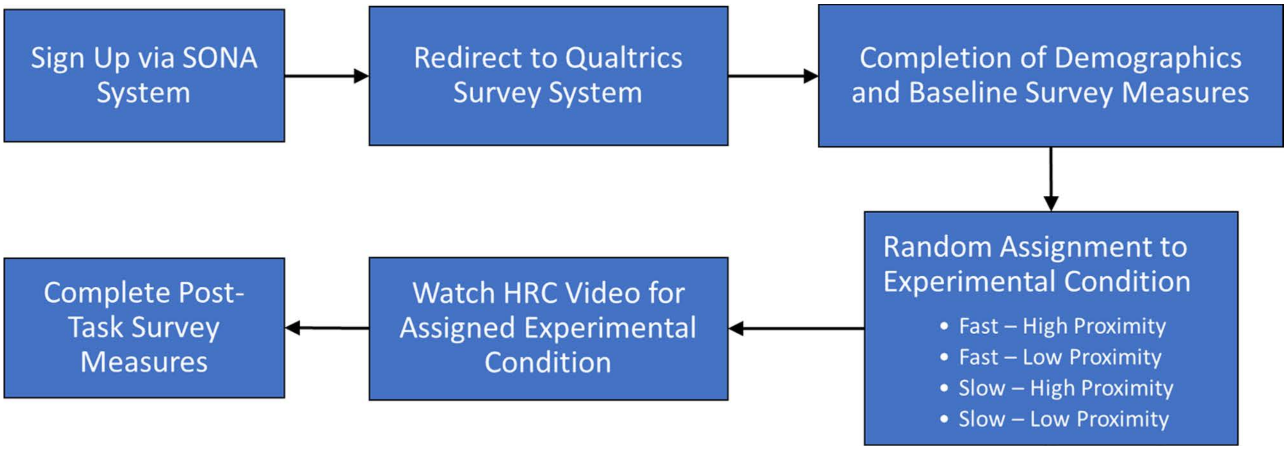

Figure 2. Flowchart of experimental procedure.

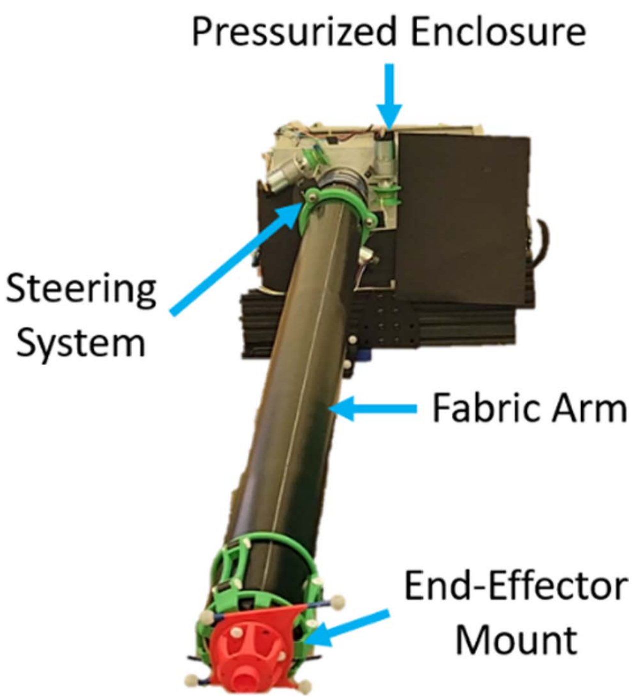

Figure 3. Soft-growing manipulator arm robotic system used in current study.

by digitally altering the speed of the recorded vignettes, rather than by recording separate videos that could have inadvertently introduced unmeasured confounding variables. In the *slow condition*, the real-time recorded versions of the original low and high proximity vignettes were maintained. For the *fast conditions*, the speed was digitally increased by 75% for the close and far proximity vignettes. This was the maximum increase in video speed that resulted in an appreciably faster series of interactions while still maintaining plausibility (i.e. movements did not appear jerky or unnatural), while also avoiding any potential confounding variables that might have

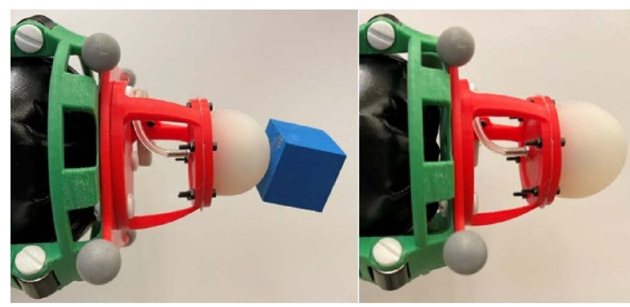

Figure 4. Soft gripper before and after inflation.

occurred with a new set of video recordings (e.g. slightly different variations in cube placement, human movements, etc.).

The Soft Robot

The robotic system used in this study was a novel, low cost, soft-growing manipulator arm (Dorosh et al., 2023; see Figure 3). The soft-growing manipulator arm has four main subsystems: a fabric arm, a pressurized enclosure, a steering system, and an end-effector mount. The robot was designed to operate at high pressures, have an entirely self-supported arm, and have the steering method located at the base of the arm. The robot can navigate within its conical-like workspace (a radius of 1.2 m, and 60 degrees of actuation in the 2D plane) by changing the length of the fabric arm and by adjusting the angle of the arm at its base. The end-effector mount has an inner and outer shell that traverses the arm as it changes length by interacting *via* roller magnets (Luong et al., 2019). The soft gripper used in this study was mounted onto the front of the end-effector mount.

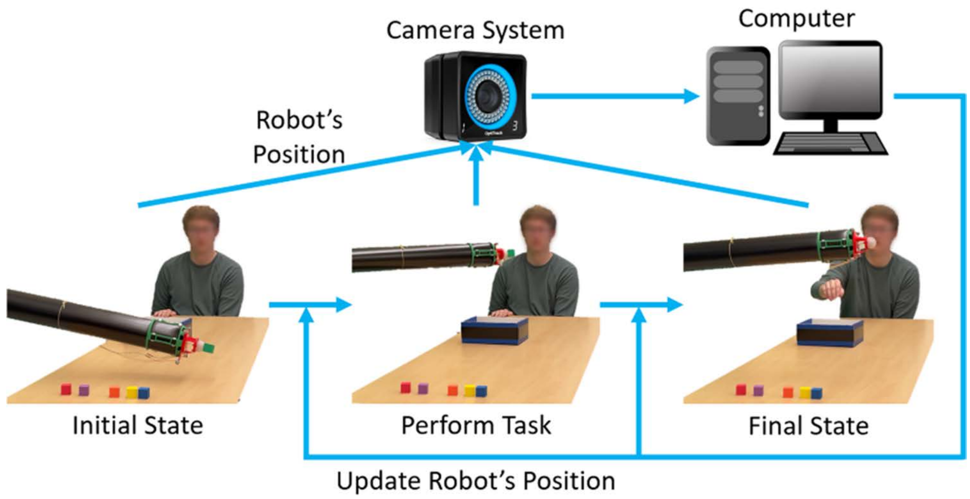

Figure 5. Depiction of how the camera system controls the robot's position during the task.

A soft inflatable gripper was utilized to move the cubes during pick and place tasks (Stroppa et al., 2021). To simplify the manipulation task, which required precise control over both position and orientation, magnets were embedded inside both the gripper and the cubes. This enabled the cube to attach to the soft gripper within a certain distance. To detach the cube, the silicone balloon inside the gripper were inflated to counteract the magnetic force (Figure 4).

In order to complete the pyramid building task described above, several waypoints were pre-defined for the robot planner, including the locations at which the robot should grasp and release the cube, and the time slots for each motion. To enable the robot arm to reach the desired points and for the gripper to actuate, a motion capture system (six OptiTrack Prime X13 cameras) was utilized to track the 3D position of the robot's end effector in real-time. This information was sent to the computer, which updated the robot's position. The feedback loop system then guided the robot to reach the desired position and to determine whether or not the soft gripper should be inflated. Figure 5 summarizes the system used to control the robotic system in this demonstration.

2.3. Measures

After participants had provided their informed consent, they were asked to provide demographic information (including prior experience with robots) and to complete a battery of baseline HRC psychosocial measures (using Qualtrics) prior to being randomly assigned to view one of the four experimental condition videos. Following the video, participants were asked to complete the same set of psychosocial measures to evaluate changes over time due to exposure to the novel soft-growing robot. For all measures noted below, mean responses were used to create an overall scale score for each variable.

Prior Robot Experience (Pre-Test Only)

The extent of prior robot experience was assessed using the 4-item scale of Schaefer (2016). Using a 5-point Likert scale (1-*none at all* to 5-*a great deal*), participants indicated how much they had observed robots on TV or in movies, interacted with robots, built robots, or controlled robots.

Perceived Safety Hazards

Perceived safety hazard perceptions were measured by adapting the work environment risk sub-scale by Neal et al. (2000), which assesses dangers and risks in the physical work environment. For the purposes of this study, the referent of "workplace" was modified to "working with robots." Participants indicated their perceived level of robot-related safety risk or hazards to 3-items (one reverse coded) on a 5-point Likert scale (1-*strongly disagree* to 5-*strongly agree*).

Robot Fear

The 5-item scale by McClure (2018) was used to measure robot fear. These items began with the phrasing "I am afraid of… "and then were followed by phrasing such as "technology that I don't understand" and "robots that can make their own decisions and take their own actions." A 5-point Likert scale was used to indicate agreement (1-*strongly disagree* to 5-*strongly agree*).

Robot Anxiety

The 4-item scale for robot anxiety assessed negative emotions generated from having to use robots

(Heerink et al., 2010). Using a 5-point Likert scale (1-*strongly disagree* to 5-*strongly agree*), the items queried whether the participant was intimidated or scared of robots and whether they feared making mistakes or breaking the robot.

Robot Warmth

To gauge robot warmth, the scale by Reeves et al. (2020) was used, which lists nine traits (tolerant, warm, good natured, sincere, competent, confident, independent, competitive, and intelligent). Using a 5-point Likert scale (1-*strongly disagree* to 5-*strongly agree*), participants indicated their agreement of whether robots had that trait.

Technology-Related Job Insecurity

A 5-item scale adapted from Lee et al. (2022) assessed technology-related job insecurity, by asking whether participants felt the use of robots would give them less control over their work, make it more difficult to use their skills and abilities, result in less interesting work, or reduce their pay and create unwanted changes to their working hours. The scale used a 4-point Likert scale (1-*not at all worried* to 4-*very worried*).

Social hesitancy

To assess social hesitancy, six items from the scale created by Nomura et al. (2006) were used to gauge participant's reactions to working with robots, such as feelings of uneasiness or nervousness related to being observed operating a robot. A 5-point Likert scale (1-*strongly disagree* to 5-*strongly agree*) was used, with higher scores indicating more hesitancy toward the use of robots.

2.4. Data Analysis

All analyses were performed using SPSS. Prior to conducting tests of our hypotheses, we first screened our data for the presence of any multivariate outliers by computing the Mahalanobis distances for each participant and removing any participant who was a multivariate outlier using a $p < .001$ criteria for the chi-square distribution. This resulted in the removal of two participants. An additional eight participants were removed due to study attrition during the course of data collection, leaving a final sample of $N = 112$. Additionally, we conducted preliminary checks to confirm the normality of the data by computing skewness and kurtosis for all measured variables. None of the variables exceeded the recommended threshold of 3 for skewness or 10 for kurtosis (Brown, 2015).

In order to test Hypothesis 1, we conducted a multivariate, repeated-measures analysis of variance with the within-person factor consisting of the pre- and post-measures of our six dependent variables. The remaining Research Question and Hypotheses were tested using a multivariate ANOVA with speed and proximity as dichotomous independent variables and prior experience as a continuous moderator.

Due to the imbalanced gender distribution of participants, and because of conflicting evidence regarding possible differing levels of technology acceptance (c.f., Breakwell et al., 1986; Wong et al., 2011), we first assessed whether there were any significant differences in any of our pre- or post-measures as a function of gender, or as an interaction between gender and prior robot experience. Both of these were non-significant: $F(12, 97) = 1.55$, *ns* and $F(12, 97) = 1.62$, *ns*, respectively, suggesting no effects of gender on any of our dependent variables. Additionally, after entering gender as a control variable in our repeated measures analysis of variance, we found that its inclusion did not alter the direction or significance of the pre-post changes in attitudes, $F(6, 105) = 2.04$, *ns*. Therefore, based on recommendations (e.g. Spector & Brannick, 2011) to avoid inclusion of spurious control variables, we report our full results without this variable.

3. Results

3.1. Manipulation Checks

Results indicated that our experimental manipulations significantly affected participant perceptions of speed and distance. Participants in the slow condition rated the robot speed significantly slower ($M = 20.14$, $SD = 13.46$) compared to participants in the fast condition ($M = 30.07$; $SD = 16.43$), $F(1, 110) = 12.23$, $p < .001$, $\eta^2 = .10$. Similarly, participants in the close proximity (collaborative) condition rated the distance of the human-robot interactions as significantly closer

Table 1. Changes in robot-related attitudes following observation of the HRC task.

Outcome	Pre-Task M (SD)	Post-Task M (SD)	F (1, 111)	p	η^2
Perceived safety hazards	2.94 (.73)	2.31 (.82)	60.987	<.001	.36
Robot fear	3.40 (.87)	2.13 (.97)	145.723	<.001	.57
Robot anxiety	3.23 (.82)	2.26 (.89)	90.246	<.001	.45
Robot warmth	3.07 (.81)	2.68 (.85)	20.816	<.001	.16
Technology-related job insecurity	2.46 (.70)	2.12 (.83)	35.357	<.001	.24
Social hesitancy	2.99 (.80)	2.35 (.87)	51.841	<.001	.32

($M = 35.23$, $SD = 20.85$) than participants in the distant (cooperative) condition ($M = 44.02$; $SD = 24.56$), $F(1, 109) = 4.13$, $p = .044$, $\eta^2 = .04$.

3.2. Test of Hypothesis 1: Effects of Increased Exposure

The multivariate repeated measures ANOVA indicated that there was a significant change in robot-related attitudes following the observation of the HRC task, $F(6, 106) = 31.22$, $p < .001$, $\eta^2 = .64$. Tests of the univariate effects, as well as means, standard deviations, and effect sizes, can be found in Table 1. In support of Hypothesis 1, participants perceived fewer safety hazards associated with working with robots, expressed less anxiety and fear about robots, reported less social hesitancy about HRC, and had lower levels of technology-induced fears of job insecurity following the HRC observation with the soft robot compared to their original baseline levels. Counter to expectations, however, following the HRC observation, participants reported less warmth toward robots.

3.3 Test of Research Question 1 and Hypothesis 2: Main Effects of Proximity and Speed

In exploring Research Question 1, the multivariate ANOVA indicated no significant effects of proximity on participant attitudes, $F(6, 101) = 0.46$, *ns*, $\eta^2 = .03$. In other words, proximity was not a significant predictor of any psychosocial reactions to the observed HRC. In support of Hypothesis 2, there were significant main effects of speed on participant attitudes, $F(6, 101) = 3.32$, $p = .005$, $\eta^2 = .17$. Specifically, fear of robots ($B = -1.56$, $p = .024$), perceived hazards ($B = -1.22$, $p = .038$), technology-induced job insecurity ($B = -1.19$, $p = .044$), and robot anxiety ($B = -1.96$, $p = .002$) were all significantly lower when observing slower HRC interactions. No significant effects were found for warmth or social hesitancy. See Table 2 for the complete set of parameter estimates.

3.4. Test of Hypothesis 3: Moderating Effects of Prior Robot Experience

Contrary to Hypothesis 3a, prior robot experience did not significantly moderate participant reactions to

Table 2. Parameter estimates and effect sizes for main and interaction effects.

Outcome	Parameter	*B*	*t*	η^2
Warmth	Intercept	2.48		
	Speed	.97	1.64	.03
	Distance	−0.02	−0.03	.00
	Prior Experience	.09	.33	.00
	Speed x Prior	−0.58	−1.91†	.03
	Distance x Prior	.15	.45	.00
Robot Fear	Intercept	2.65		
	Speed	−1.56	−2.29*	.05
	Distance	.71	.98	.01
	Prior Experience	−0.32	−1.06	.01
	Speed x Prior	.83	2.33*	.05
	Distance x Prior	−0.32	−0.84	.01
Perceived Safety Hazards	Intercept	3.14		
	Speed	−1.22	−2.10*	.04
	Distance	.07	.11	.00
	Prior Experience	−0.41	−1.60	.02
	Speed x Prior	.57	1.88†	.03
	Distance x Prior	−0.03	−0.10	.00
Social Hesitancy	Intercept	2.48		
	Speed	−0.90	−1.45	.02
	Distance	.83	1.28	.02
	Prior Experience	−0.13	−0.48	.00
	Speed x Prior	.44	1.39	.02
	Distance x Prior	−0.31	−0.91	.00
Job Insecurity	Intercept	2.57		
	Speed	−1.19	−2.03*	.04
	Distance	.58	.94	.01
	Prior Experience	−0.30	−1.16	.01
	Speed x Prior	.67	2.20*	.04
	Distance x Prior	−0.26	−0.80	.01
Robot Anxiety	Intercept	3.17		
	Speed	−1.96	−3.25*	.09
	Distance	.50	.77	.01
	Prior Experience	−0.42	−1.58	.02
	Speed x Prior	.86	2.75*	.07
	Distance x Prior	−0.24	−0.71	.01

Note: †$p < .10$, *$p < .05$;. Speed: 0 = fast; 1 = slow; Distance: 0 = near; 1 = far.

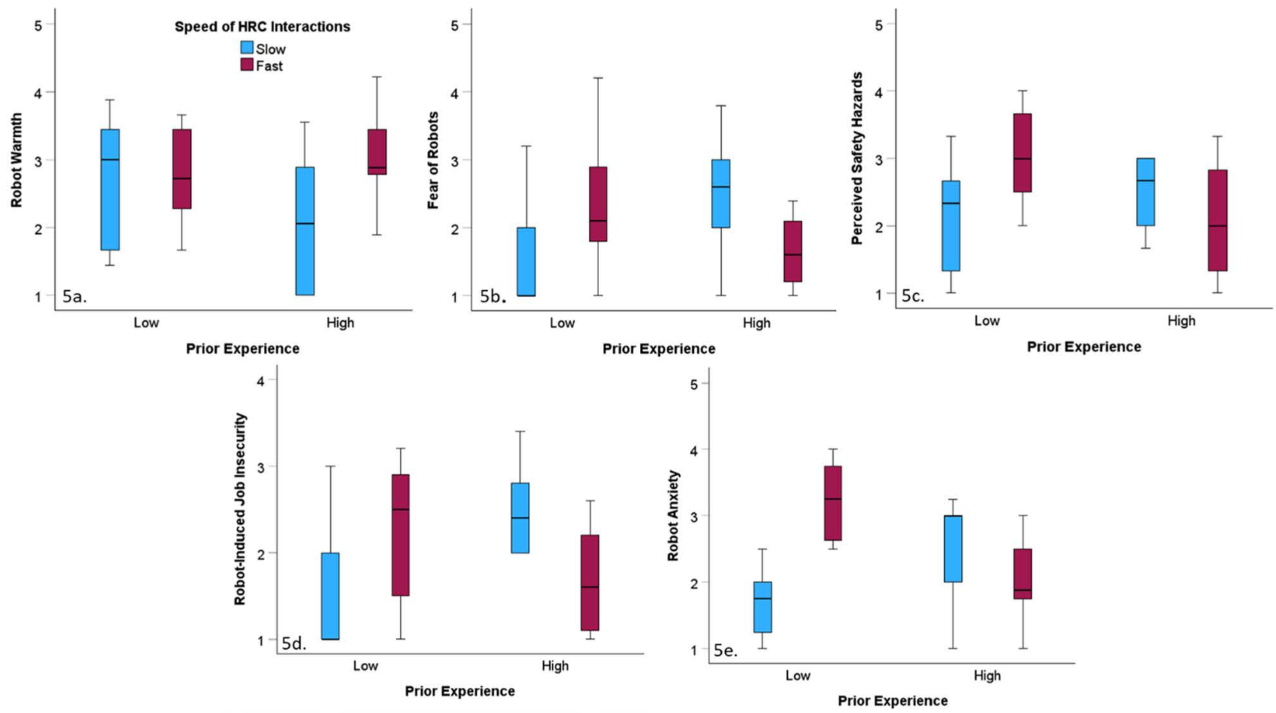

Figure 6. Moderating effects of prior experience on reactions to speed manipulation.

HRC proximity, $F(6, 101) = 0.94$, *ns*, η^2=.02. However, in support of Hypothesis 3b, there was a significant multivariate interaction effect between prior robot experience and our speed manipulation, $F(6, 101) = 3.15$, $p < .01$, η^2=.16. Specifically, as shown in Table 2, prior experience with robots significantly attenuated the effects of speed on perceived robot warmth, fear, safety hazards, anxiety, and robot-induced job insecurity. The form of the significant interactions is further depicted in Figure 6, where prior experience is plotted at +/- 1 SD from the mean, as recommended by Aiken and West (1991). As can be seen, when prior experience with robots is low, faster HRC is associated with less robot warmth, and more fear, safety hazards, anxiety, and job insecurity. However, among participants who had higher levels of prior robot experience, these effects were reversed. In other words, participants with greater prior robot experience reacted more positively to the faster robots, whereas the opposite was the case for participants with low prior experience.

4. Discussion

4.1. Summary of Findings and Implications

Adoption of collaborative robots into occupational settings has remained low, often due to psychosocial barriers such as lack of trust and fears of technology-induced obsolescence (Görke et al., 2017). Recent advancements in the development of novel soft robots (Rus & Tolley, 2015) necessitate a better understanding of psychosocial reactions to working alongside these newer forms of robots, particularly given that the vast majority of prior research has involved assessments of and interactions with traditional rigid manipulators (see Jørgensen et al., 2022 for a rare exception). Thus, the purpose of our research was to examine how psychological reactions to observing human interactions with a novel soft growing robot would change over time and vary as a function of prior experience with robots, speed of the observed HRC, and level of HRC proximity.

We expected (*Hypothesis 1*) that attitudes toward the soft robot would improve from pre- to post-task (i.e., as participants gained exposure to the novel soft growing robot). In support of this, the initial results indicated that increasing exposure to novel soft robots results in generally more positive attitudes. Across nearly every outcome measured, participant attitudes were more positive following the viewed HRC interaction with the soft robot compared to their baseline levels. Specifically, participants perceived fewer safety hazards associated with working with robots, expressed less anxiety and fear about robots, reported less social hesitancy about HRC, and had lower levels of technology-induced fears of job insecurity following the HRC observation.

Interestingly, the exception to this outcome was perceived robot warmth, which decreased from baseline attitudes to post-observation of the robot. This difference may be due to the observed tendency for humans to anthropomorphize robots (Złotowski et al., 2015). However, Kahn et al. (2007) described six features of HRI necessary to facilitate such anthropomorphism: autonomy, imitation, intrinsic moral value, moral accountability, privacy, and reciprocity. Therefore, once our participants viewed the robot used in this study (a robotic arm with no discernable humanoid features), their initial baseline expectations may have been disconfirmed, resulting in a decrease in rated warmth.

The answer to our exploratory *Research Question 1* indicated that, contrary to extant research involving rigid robots, participant reactions did *not* vary as a function of the distance between the human and robot. In other words, attitudes were uniform regardless of whether the task involved cooperation (i.e. physically separated completion of the joint task) versus actual collaboration (i.e., exchange of forces during the HRC). The fact that proximity was *unrelated* to attitudes toward the soft robot may be a positive indicator. While some research (e.g. Arai et al., 2010; Kim & Mutlu, 2014; MacArthur et al., 2017; Stark et al., 2018) indicates that closer HRC proximity is associated with more negative participant reactions, such research has been conducted with rigid robots. Yet, to achieve true collaboration between humans and robots, an exchange of forces (i.e. close proximity joint completion of tasks) is required. Our preliminary findings indicate this may be possible with a soft robot without leading to negative participant reactions; however, see our acknowledged limitations below and need for additional research to further explore this possibility.

Further, and as hypothesized in *Hypothesis 2*, participant reactions were generally more positive under slower HRC interactions compared to the faster condition. From a human factors perspective, although the results of this experiment provide only preliminary evidence, they indicate that speed remains a relevant factor to consider when predicting how humans might react to HRC interactions with soft robots. Namely, faster speeds resulted in more self-reported concerns about physical safety hazards, greater robot fears and anxiety, and more worries about robots replacing human jobs.

Finally, as predicted by *Hypothesis 3*, the level of prior robot experience moderated many of the relationships between speed and participant reactions, such that participants with greater prior robot experience reacted more positively to the faster robots whereas the opposite was true for low prior experience participants. These moderating effects suggest that a one-size-fits-all solution with speed is not feasible, and may prompt the need for the development of variable speed robots that can be adjusted as a function of user experience levels. Namely, as users are first gaining comfort with and trust in the robot, slower speeds may be more conducive to developing these positive attitudes; on the other hand, as user experience grows, more positive psychosocial reactions may occur with somewhat faster HRC interactions.

4.2. Limitations and Directions for Future Research

As technological advances continue within the field of soft robotics, and as these NextGen robots are increasingly integrated within occupational settings (e.g. Dorosh et al., 2023), applied research such as the current study is required to evaluate the extent to which prior research (primarily involving rigid robotic manipulators) generalizes to HRC with these novel soft growing robots. Nevertheless, a limitation of our current study is that only self-reported attitudinal reactions were obtained. To address this, future research should utilize objective physiological measurements of stress reactions (e.g. heart rate variability, galvanic skin response, and cortisol levels) while manipulating speed to further confirm this result. Additionally, such research should involve actual physical interactions between research participants and the soft robot, rather than viewing prerecorded vignettes.

While it is encouraging that proximity was *unrelated* to attitudes toward the soft robot, it is important to acknowledge a further limitation with our study—participants only *viewed* HRC interactions that varied in speed and proximity, rather than *actively engaged* in HRC interactions that varied along these dimensions. Additionally, our proximity manipulation only had two discrete conditions (i.e. dropping the cube in a box vs. handing the cube to the worker). Other relevant proximity manipulations would be worthwhile to explore (e.g. the worker catching a cube dropped by a robot arm).

Moreover, the robot used in our study was not locomotive. Other research (e.g. Story et al., 2022) has failed to find hypothesized proximity effects when investigating reactions to HRC where the robots or robotic arms are fixed in place. Thus, further experimental research is needed that would allow participants to actually engage in interactions with the soft robot to further disentangle these plausible alternative explanations. Similarly, research is needed that also directly compares interactions with both rigid and soft robotic manipulators.

Such in-person experiments would be more ideal compared to our video vignette study. However, because this is the first study to specifically investigate speed, proximity, and prior experience as factors affecting psychosocial reactions to a soft growing robot, this initial study serves as a proof of concept that such an in-person experiment is worth the time, funding, and effort that would be required to conduct such a study. For example, a 2 (soft vs. rigid) × 2 (fast vs. slow) × 2 (close vs. distant) design results in eight unique conditions. Because only one participant could be run per session, a minimum sample size of $N = 25$ individuals in each cell would require 200 participants, necessitating at least 200 h in the robotic laboratory to run this experiment. This is in addition to grant funding to support the participant costs and robotic supplies. While this is our intended next step, such a study was not feasible to do this before establishing the proof of concept in the current initial study. Indeed, the fact that significant effects were observed even with the current video vignette design suggests that we might see larger effects when participants are given the opportunity to actually physically interact with the different robots and under the differing conditions.

The soft growing manipulator discussed in this paper is still in the early stages of development, and therefore our data for the current study relied on a convenience sample of undergraduate students, rather than a more ecologically valid sample of workers in an occupational setting, and used a relatively simplistic cube-stacking task. However, it is important to note that such picking and placing tasks are commonplace in the workplace in a variety of occupations and industries. For example, Amazon sponsored a series of Robotics Challenges specifically targeting picking and placing tasks to address the high need for robots to accomplish this seemingly simple task. In the case of transportation and warehousing, robots are needed to work alongside humans to pick and places objects (e.g. boxes and packages) in a specific way.

Nevertheless, moving forward, our engineering group will focus on optimizing our robot's performance, which will include increasing the variety of controllable speeds, improving position precision, and reducing vibration. As that progresses, we plan to conduct future studies manipulating speed, proximity, and type of manipulator to extend these preliminary results and allow for better direct comparisons with traditional rigid robots, as well as while engaged in more complex tasks. Moreover, we plan to collect reaction data from assisted living caregivers, as well as agricultural employees working alongside these newer robot forms in tree orchards in order to enhance the external generalizability of our current laboratory-based results.

We also recommend that future research obtain a more gender-balanced sample in order to avoid any confounding or bias due to potentially varying levels of technology acceptance between groups. Some previous research (e.g. Breakwell et al., 1986) has found gender differences with respect to technology acceptance, although other more recent research (e.g. Kim et al., 2012; Wong et al., 2011) has not. Our preliminary analyses evaluating the effects of gender did not reveal any significant effects. Nevertheless, to better facilitate detection of such effects, further research in this area should ensure more balanced sampling.

5. Conclusions

Information regarding psychosocial reactions to working alongside NextGen robots, as well as how user reactions may differ as a function of technical design features (e.g. speed, haptics, form, and proximity), can provide valuable insight into improving soft robotic design in occupational settings. Our findings indicate that speed remains a salient factor when evaluating psychosocial reactions to HRC, such that in general more negative reactions occur in response to faster interactions (supporting H2). Interestingly, individuals with greater prior experience with robots were less affected by the speed manipulation, indicating that as humans gain more experience working alongside and interacting with robots, speed may be less of a limiting factor (supporting H3). This outcome is aligned with our pre-post effects indicating that overall attitudes became significantly more positive following observation of the HRC interaction compared to baseline levels (in support of H1). Moreover, and in contrast to the effects of proximity (RQ1) seen in prior research with traditional rigid robots, participant reactions to the soft robot in our study did not vary as a function of proximity, thus suggesting closer interactions without adverse effects on psychosocial reactions may be possible with this newer class of robots. Given these findings, further exploration of the advantages posed by novel soft growing robots may have the potential to address several current limitations in the field of HRC, including not only safety, functionality, cost, and weight, but also human psychosocial factors. These HRC challenges are not just technical problems in academia; rather, understanding challenges at the human-robot interface will determine how industry robots must look and perform in the future world of work.

Disclosure Statement

The authors declare no conflict of interest.

Conflict of interest

The authors declare no conflict of interest.

Funding

Funding for this research was supported by a mini-grant from the WSU Office of Research awarded to the first author and Cougar Cage funding from WSU and the Palouse Club awarded to the fifth author.

ORCID

Tahira M. Probst http://orcid.org/0000-0002-2789-4492
Rebecca J. Lindgren http://orcid.org/0000-0003-1594-5202

References

Arai, T., Kato, R., & Fujita, M. (2010). Assessment of operator stress induced by robot collaboration in assembly. *CIRP Annals*, *59*(1), 5–8. https://doi.org/10.1016/j.cirp.2010.03.043

Block, A. E., & Kuchenbecker, K. J. (2019). Softness, warmth, and responsiveness improve robot hugs. *International Journal of Social Robotics*, *11*(1), 49–64. https://doi.org/10.1007/s12369-018-0495-2

Breakwell, G. M., Fife-Schaw, C., Lee, T., & Spencer, J. (1986). Attitudes to new technology in relation to social beliefs and group memberships: A preliminary investigation. *Current Psychological Research & Reviews*, *5*(1), 34–47. https://doi.org/10.1007/BF02686595

Bridger, R. S., Brasher, K., Dew, A., Sparshott, K., & Kilminster, S. (2010). Job strain related to cognitive failure in naval personnel. *Ergonomics*, *53*(6), 739–747. https://doi.org/10.1080/00140131003672031

Collins, K. (2015, February 2). Robot kills worker at Volkswagen plant. *Wired*. Retrieved from https://www.wired.co.uk/article/robot-kills-man-at-volkswagen-factory

Corbato, C. H., Bharatheesha, M., Van Egmond, J., Ju, J., & Wisse, M. (2018). Integrating different levels of automation: Lessons from winning the amazon robotics challenge 2016. *IEEE Transactions on Industrial Informatics*, *14*(11), 4916–4926. https://doi.org/10.1109/TII.2018.2800744

De Graaf, M. M., & Allouch, S. B. (2013). Exploring influencing variables for the acceptance of social robots. *Robotics and Autonomous Systems*, *61*(12), 1476–1486. https://doi.org/10.1016/j.robot.2013.07.007

Dorosh, R., Allen, J., He, Z., Ninatanta, C., Coleman, J., Spieker, J., Tuck, E., Kurtz, J., Zhang, Q., Whiting, M. D., Luo, J., Karkee, M., & Luo, M. (2023). *Design, modeling, and control of a low-cost and rapid response soft-growing manipulator for orchard operations* [Paper presentation].IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Detroit, MI.

Dzedzickis, A., Subačiūtė-Žemaitienė, J., Šutinys, E., Samukaitė-Bubnienė, U., & Bučinskas, V. (2021). Advanced applications of industrial robotics: New trends and possibilities. *Applied Sciences*, *12*(1), 135. https://doi.org/10.3390/app12010135

Felknor, S. A., Vietas, J. A., & Streit, J. M. K. (2022). Impact of new technologies on occupational health and well-being. *International Journal of Environmental Research and Public Health*, Retrieved from https://www.mdpi.com/journal/ijerph/special_issues/_impact_of_new_technologies_on_occupational_health

Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerization? *Technological Forecasting and Social Change*, *114*, 254–280. https://doi.org/10.1016/j.techfore.2016.08.019

Görke, M., Blankemeyer, S., Pischke, D., Oubari, A., Raatz, A., & Nyhuis, P. (2017). Sichere und akzeptierte Kollaboration von Mensch und Maschine. *Zeitschrift Für Wirtschaftlichen Fabrikbetrieb*, *112*(1-2), 41–45. https://doi.org/10.3139/104.111668

Halpern, D., & Katz, J. E. (2012). Unveiling robotophobia and cyber-dystopianism: The role of gender, technology and religion on attitudes towards robots. In H. Yanco (Ed.), *Proceedings of the Seventh Annual ACMIEEE International Conference on Human-Robot Interaction* (pp. 139–140). ACM.

Heerink, M., Kröse, B., Evers, V., & Wielinga, B. (2010). Assessing acceptance of assistive social agent technology by older adults: The Almere model. *International Journal of Social Robotics*, *2*(4), 361–375. https://doi.org/10.1007/s12369-010-0068-5

Jørgensen, J., Bojesen, K. B., & Jochum, E. (2022). Is a soft robot more "natural"? Exploring the perception of soft robotics in human–robot interaction. *International Journal of Social Robotics*, *14*(1), 95–113. https://doi.org/10.1007/s12369-021-00761-1

Kahn, P. H., Jr, Ishiguro, H., Friedman, B., Kanda, T., Freier, N. G., Severson, R. L., & Miller, J. (2007). What is a human? Toward psychological benchmarks in the field of human–robot. *Interaction Studies: Social Behaviour and Communication in Biological and Artificial Systems*, *8*(3), 363–390. https://doi.org/10.1075/is.8.3.04kah

Kim, J., Christodoulidou, N., & Brewer, P. (2012). Impact of individual difference and consumers' readiness on likelihood of using self-service technologies at hospitality settings. *Journal of Hospitality & Tourism Research*, *36*(1), 85–114. https://doi.org/10.1177/1096348011407311

Kim, Y., & Mutlu, B. (2014). How social distance shapes human–robot interaction. *International Journal of Human-Computer Studies*, *72*(12), 783–795. https://doi.org/10.1016/j.ijhcs.2014.05.005

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

Kulic, D., & Croft, E. (2005). *Anxiety detection during human-robot interaction* [Paper presentation].2005 IEEE/RSJ International Conference on Intelligent Robots and Systems, August. In (pp. 616–621). IEEE. https://doi.org/10.1109/IROS.2005.1545012

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering*, *6*(4), 239–242. https://doi.org/10.1007/s12599-014-0334-4

Lee, H. J., Probst, T. M., Bazzoli, A., & Lee, S. (2022). Technology advancements and employees' qualitative job insecurity in the Republic of Korea: Does training help? employer-provided vs. self-paid training. *International Journal of Environmental Research and Public Health*, *19*(21), 14368. https://doi.org/10.3390/ijerph192114368

Linden, D. V. D., Keijsers, G. P., Eling, P., & Schaijk, R. V. (2005). Work stress and attentional difficulties: An initial study on burnout and cognitive failures. *Work & Stress*, *19*(1), 23–36. https://doi.org/10.1080/02678370500065275

Luong, J., Glick, P., Ong, A., DeVries, M. S., Sandin, S., Hawkes, E. W., & Tolley, M. T. (2019, April). *Eversion and retraction of a soft robot towards the exploration of coral reefs* [Paper presentation].2019 2nd IEEE International Conference on Soft Robotics (RoboSoft), In (pp. 801–807). IEEE. https://doi.org/10.1109/ROBOSOFT.2019.8722730

MacArthur, K. R., Stowers, K., & Hancock, P. A. (2017). Human-robot interaction: Proximity and speed—slowly back away from the robot. ! In *Advances in Human Factors in Robots and Unmanned Systems: Proceedings of the AHFE 2016 International Conference on Human Factors in Robots and Unmanned Systems*, July 27–31, 2016 (pp. 365–374). Springer International Publishing.

McClure, P. K. (2018). "You're fired," says the robot. *Social Science Computer Review*, *36*(2), 139–156. https://doi.org/10.1177/0894439317698637

Mordor Intelligence. (2021). Soft robotics market - Growth, trends, COVID-19 impact, and forecasts (2021–2026). Retrieved from https://www.reportlinker.com/p06155634/Soft-Robotics-Market-Growth-Trends-COVID-19-Impact-and-Forecasts.html

Müller-Abdelrazeq, S. L., Schönefeld, K., Haberstroh, M., & Hees, F. (2019). Interacting with collaborative robots—A study on attitudes and acceptance in industrial contexts. In: O. Korn (Eds) *Social robots: Technological, societal and ethical aspects of human-robot interaction*. Human–Computer Interaction Series. Springer. https://doi.org/10.1007/978-3-030-17107-0_6

Neal, A., Griffin, M. A., & Hart, P. M. (2000). The impact of organizational climate on safety climate and individual behavior. *Safety Science*, *34*(1-3), 99–109. https://doi.org/10.1016/S0925-7535(00)00008-4

Negrello, F., Mghames, S., Grioli, G., Garabini, M., & Catalano, M. G. (2019). A compact soft articulated parallel wrist for grasping in narrow spaces. *IEEE Robotics and Automation Letters*, *4*(4), 3161–3168. https://doi.org/10.1109/LRA.2019.2925304

Nomura, T., Suzuki, T., Kanda, T., & Kato, K. (2006). Measurement of negative attitudes toward robots. *Interaction Studies. Social Behaviour and Communication in Biological and Artificial Systems*, *7*(3), 437–454. https://doi.org/10.1075/is.7.3.14nom

Nomura, T., Suzuki, T., Kanda, T., Yamada, S., & Kato, K. (2011). Attitudes toward robots and factors influencing them. In K. Dautenhahn & J. Saunders (Eds.), *Advances in interaction studies. New frontiers in human–robot interaction* (Vol. 2, pp. 73–88). John Benjamins Publishing Company.

Pérez, L., Rodríguez-Jiménez, S., Rodríguez, N., Usamentiaga, R., García, D. F., & Wang, L. (2020). Symbiotic human–robot collaborative approach for increased productivity and enhanced safety in the aerospace manufacturing industry. *The International Journal of Advanced Manufacturing Technology*, *106*(3-4), 851–863. https://doi.org/10.1007/s00170-019-04638-6

Petitta, L., Probst, T. M., Ghezzi, V., & Barbaranelli, C. (2019). Cognitive failures in response to emotional contagion: Their effects on workplace accidents. *Accident; Analysis and Prevention*, *125*, 165–173. https://doi.org/10.1016/j.aap.2019.01.018

Reeves, B., Hancock, J., & Liu, X. (2020). Social robots are like real people: First impressions, attributes, and stereotyping of social robots. *Technology, Mind, and Behavior*, *1*(1), 1–13. https://doi.org/10.1037/tmb0000018

Rus, D., & Tolley, M. T. (2015). Design, fabrication and control of soft robots. *Nature*, *521*(7553), 467–475. https://doi.org/10.1038/nature14543

Schaefer, K. E. (2016). Measuring trust in human robot interactions: Development of the "trust perception scale-HRI". In R. Mittu, D. Sofge, A. Wagner, & W. F. Lawless. (Eds.), *Robust Intelligence and Trust in Autonomous Systems* (pp. 191–218). Springer.

Schmidtler, J., Knott, V., Hölzel, C., Bengler, K., Schlick, C. M., & Bützler, J. (2015). Human-centered assistance applications for the working environment of the future. *Occupational Ergonomics*, *12*(3), 83–95. https://doi.org/10.3233/OER-150226

Spector, P. E., & Brannick, M. T. (2011). Methodological urban legends: The misuse of statistical control variables. *Organizational Research Methods*, *14*(2), 287–305. https://doi.org/10.1177/1094428110369842

Stark, J., Mota, R. R., & Sharlin, E. (2018, March). *Personal space intrusion in human-robot collaboration* [Paper presentation].Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction (pp. 245–246). https://doi.org/10.1145/3173386.3176998

Story, M., Webb, P., Fletcher, S. R., Tang, G., Jaksic, C., & Carberry, J. (2022). Do speed and proximity affect human-robot collaboration with an industrial robot arm? *International Journal of Social Robotics*, *14*(4), 1087–1102. https://doi.org/10.1007/s12369-021-00853-y

Stroppa, F., Selvaggio, M., Agharese, N., Blumenschein, L. H., Hawkes, E. W., & Okamura, A. M. (2021). Shared-control teleoperation paradigms on a soft growing robot manipulator. *arXiv preprint arXiv:2108.00677*

Weiss, A., Bernhaupt, R., Tscheligi, M., & Yoshida, E. (2009). *Addressing user experience and societal impact in a user study with a humanoid robot* [Paper presentation]. In Proceedings of the Symposium on New Frontiers in Human-Robot Interaction (pp. 150–157). Edinburgh, Scotland.

Wong, D. H., Yap, K. B., Turner, B., & Rexha, N. (2011). Predicting the diffusion pattern of internet-based communication applications using bass model parameter estimates for email. *Journal of Internet Business*, *9*, 26–50.

Xing, Z., Zhang, J., McCoul, D., Cui, Y., Sun, L., & Zhao, J. (2020). A super-lightweight and soft manipulator driven by dielectric elastomers. *Soft Robotics*, *7*(4), 512–520. https://doi.org/10.1089/soro.2018.0134

Yam, K. C., Tang, P. M., Jackson, J. C., Su, R., & Gray, K. (2023). The rise of robots increases job insecurity and maladaptive workplace behaviors: Multimethod evidence. *The Journal of Applied Psychology*, *108*(5), 850–870. https://doi.org/10.1037/apl0001045

Złotowski, J., Proudfoot, D., Yogeeswaran, K., & Bartneck, C. (2015). Anthropomorphism: Opportunities and challenges in human–robot interaction. *International Journal of Social Robotics*, *7*(3), 347–360. https://doi.org/10.1007/s12369-014-0267-6