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Dynamic Graphical Signage Improves Response Time and Decreases Negative Attitudes towards Robots in Human-Robot Co-working

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Abstract. Collaborative robots, or ‘co-bots’, are a key driving technology that will blur the boundaries between traditional manual and automated manufacturing processes. However, to achieve full potential of new technology, human operators need confidence in robotic co-worker technologies and their capacities. In this experiment, we investigate the impact of screen based dynamic instructional signage on 39 participants from a manufacturing assembly line. The results provide evidence that dynamic signage helps to improve response time for the experimental group with task-relevant signage compared to control group with no signage. Furthermore, the experimental group’s negative attitudes towards robots decreased significantly with increasing accuracy on the task after interaction with the robot.

1 Introduction

The manufacturing sector is poised to undergo massive change, with Industry 4.0, the Internet of Things, and the Digital Agenda all leading toward greater digitalisation and connectivity of processes. Collaborative robots, or ‘co-bots’, are a key driving technology that will blur the boundaries between traditional manual and automated manufacturing processes. Combining the flexibility of the human workforce with the precision and repeatability of robotics allows shared workspaces to emerge where uncaged robots and humans interact directly. The development of intuitive and natural interfaces, collaboratively with users, will lead to greater levels of human-robot interaction, allowing the operation and reconfiguration of complex robotic systems with less training and shorter setup times.

As the requirements on autonomy, complexity and safety of robots increase, human operators need to develop confidence in robotic collaborative processes and understand the capacities of the robots they are working with so that effective collaboration can occur. One of the essential requirements for this confidence to be built is an appropriate level of trust [1, 2]. Too low or too high a level of trust can lead to errors and greater task completion times [3]. Another issue is that, although robots in manufacturing are not a new phenomenon, workers can still feel threatened by their presence and perceived control of the working environment. Feeling out of control, especially in situations perceived as threatening, can also result in higher stress levels [4, 5]. Whereas understanding the requirements of unfamiliar situations, having the necessary knowledge and information, can result in individual empowerment and sense of control [6], as well as a decrease in stress levels [5, 7, 8]. Finally, an individual's cognitive load is often already high in manufacturing [9] and there can be little capacity beyond undertaking a complex activity for monitoring co-workers progress (human or automated). This issue is exacerbated if users feel they do not have enough information or training to undertake a task. While increased cognitive load can lead to decreased concentration on the task performance and increased number of accidents [10, 11], establishing effective measures, in fact, can reduce the amount of information necessary for efficient decision-making [12].

From the issues discussed above, it is evident that effective information communication to aid human–robot interaction in manufacturing settings can have a positive role to play [13]. Information communication via graphical signage can be a viable tool in improving issues around human robot collaboration. The main merits of graphical signage are that it (i) displays clear instructions for individuals with little or no prior experience [14] [15], (ii) does not depend on language as opposed to written instructions, making it suitable for multicultural environments and beneficial for non-native speakers [16], (iii) does not depend on voice control making it suitable for noisy environments such as factories, and (iv) decreases cognitive load and need to process less information compared to written instructions [17]. Information communication has been proven to be an effective way to increase human well-being; for example, providing concise and clear information in the healthcare context increase patients eagerness to discuss their situation and prompt questions

[18] leading to feelings of being in control and able to make important decisions [6], which in turn can decrease experienced stress [5, 7, 8]. An alternative option is social cues (facial expressions, body language, pitch of voice) which have similar benefits to graphical signage [19]. However, for robots, which do not having animate like form such as robotic arms, exhibiting social cues becomes too ambiguous and unreliable as a form of providing information. This type of manipulation is best used in studies with anthropomorphic robots (such as Baxter).

The aim of the current research was to further extend the findings of graphical signage from Eimontaite et al., (2016)[20] by examining the effects of dynamic screen-based graphical signage on collaborative human-robot interaction within a manufacturing workforce. We explored this by observing the behaviour of employees from our industrial collaborators with little or no experience in working with robotics in a manufacturing context. It was expected experimental group participants, who were presented with task relevant dynamic signage, will have higher task completion accuracy and lower response times compared with control group participants with no signage. Furthermore, we predicted that negative attitudes towards robots and robot anxiety will decrease after the experiment for both experimental and control groups, but that the decrease will be greater for the experimental group participants.

2 Methods

2.1 Participants

Forty low skilled workers (9 female) from the partner's workforce participated in the experiment across two groups (20 per group). One participant was removed from the analysis due to leaving the pre-test questionnaire empty resulting in 39 participants for the final analysis. The mean age of participants was 38.63 (SD = 13.30). Participants had no prior knowledge of using robots and they were not exposed to the signage before the experiment. This participant population was ideal for the study, as the company was underway of installing its first collaborative robotics cell, but the employees have not been trained or interacted with a robot before. The work was approved by the University of Sheffield Ethics Committee.

2.2 KUKA iiwa Lightweight Arm

In this study, a KUKA Intelligent Industrial Work Assistant (iiwa; KUKA Roboter GmbH) was used for the human–robot co-working task. The KUKA iiwa is developed as a collaborative robot, specifically allowing direct human–robot interaction, and has a set of configurable safety measures suited to co-working (Fig. 2). For this study the robot was set to be operated in a compliant safe mode 'T1' with limits on speed and a requirement for human monitoring. The KUKA iiwa was controlled via our own Application Programming Interface (API) [21].

2.3 Design of the Graphical Signage

For the project a set of bespoke graphical symbols was refined from earlier paper based solutions [20] and developed further into dynamic graphical signage to provide real time information to the user about robot operational processes. The signage was collaboratively designed in workshops with workers from the industry partner, before being refined. Dynamic graphical signage visually represented human-robot interaction events to provide a co-worker with key information, such as when it is safe to touch the robot, the expected speed of robot movement, and operational area, etc.

During the experiment, screen based dynamical graphic signage was presented on the computer monitor (20 inch screen diameter) on the right side of the robot 70 cm away from the desk edge where participants were standing. Experimental group participants were presented with animated gifs with the information about robotic arm (direction of robot movement (x and y axes), the speed and reach of robot, applied force from the user to navigate robot; each presented for 30 sec at the start of interaction with the robot). Being dynamic allowed the signage to communicate nuanced information relating to participants interaction with the robot. During the trials, the signage indicated when participants should navigate the robot over the tube, and when robot was completing the process on its own (Fig. 1). Control group participants were presented with blank screen during the experiment.

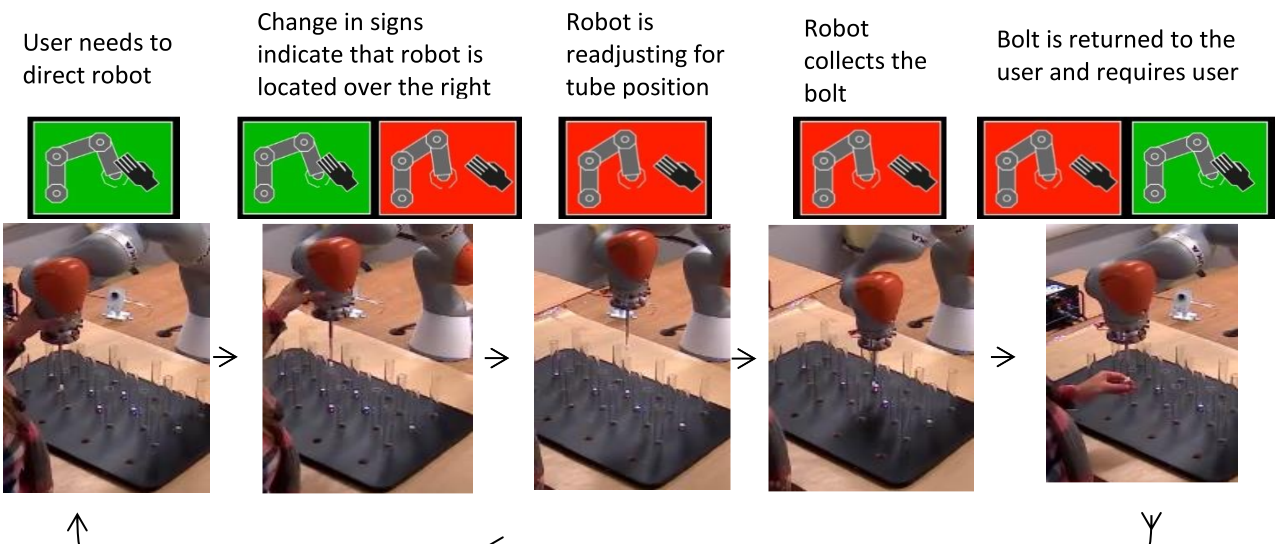

Fig. 1. Diagram of dynamic signage from "touch" to "do not touch"

2.4 Measures

The following measures were used in the experiment:

Negative Attitudes towards Robots Scale (NARS). This scale consisting of 14 statements was developed by Nomura and colleagues [22]. In this experiment the sub-scales of attitudes towards interactions with robots and towards social influences were administered pre- and post-experiment where participants had to indicate their agreement with each of the statements on five-point scale (from 1 – strongly disagree to 5 – strongly agree).

Robot Anxiety Scale (RAS). This scale measures anxiety affecting participants' interactions with robots [23]. Only the sub-scale measuring anxiety towards the behavioural characteristics of robots were conducted pre- and post-experiment. In this questionnaire, participants indicate how anxious they feel about each statement on a six-point scale from 1 "I do not feel anxiety at all" to 6 "I feel very anxious".

Behavioural Measures. The following behavioural measures were the main interest of the study: 1) participant accuracy (collected bolts/number of trials), and 2) time taken to complete the task. These measures serve as behavioural indexes of task achievement.

To control for confounding variables, measures of participants risk taking attitudes [24], their experience with robotics [25], computer use frequency, and programming expertise were taken. Furthermore, a post experiment questionnaire asked participants to indicate which signs they have seen during the experiment (attention measure).

All the questionnaires in this study are computerized and were presented through the Qualtrics Insight Platform.

2.7 Procedure

The study was conducted on site at the industrial partner's factory, in one of their process development rooms in order to achieve a realistic working experience. Upon arrival at the experiment, participants signed a consent form and filled in a questionnaire measuring their demographic information and the control variables (participant's robot anxiety (RAS), negative attitude towards robots (NARS), computer use frequency, age, and programming experience, risk taking attitude and experience with robots).

A process to be undertaken by participants was described in the following way: "on the table there are 16 narrow tubes and 6 of them contain M5 bolts (Fig 2). These bolts need to be put into a collection box, however they are inaccessible to the human [the tubes being too narrow to allow access by hand], and, although the robot can reach and pick the bolts, it is unable to locate in which tubes they are placed". Participants could only complete the task by collaborating with the robotic arm and they were not provided with any additional verbal information. While experimental group were provided with the screen based dynamic graphical signage, control group were presented with blank screen. Although effective collaboration requires good communication, the task was basic and intuitive to complete without additional information just knowing the aim. In fact, all participants successfully completed at least two trials. In this particular study, control group was used to compare the effects of signage effects vs. no signage on participants' wellbeing (attitudes and anxiety towards robot) and performance (accuracy and response time).

This scenario was not a real application of the existing process, but an example demonstrating possible ways humans and robots can collaborate on different processes in manufacturing. The maximum time to complete the task was 10 min. The experiment was recorded on video to obtain behavioural measures. During the experiment, a collaborator observes the participants' performance as a safety measure in case the experiment needed to be aborted.

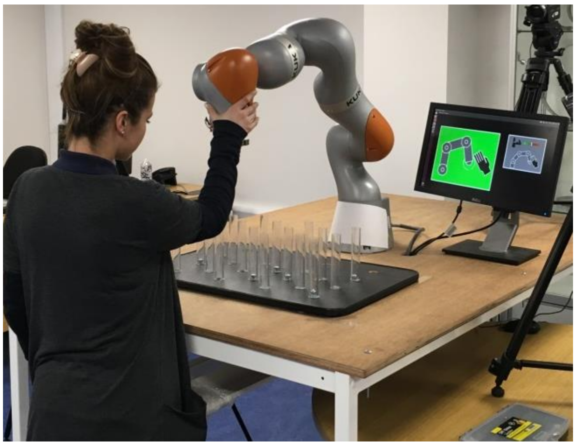

Fig. 2. KUKA iiwa and experimental task setup

Participants were informed that they are going to be video recorded during the experiment, and the material collected will be used for data coding and further statistical analysis. However, measures were taken to keep the data anonymous and confidential.

After the main part of the experiment, participants' robot anxiety (RAS) and negative attitudes towards robots (NARS) were measured once again. Participants had to fill in signage effectiveness and recollection questionnaire as a control measure for their attention to signage. The whole experiment lasted around 30 minutes.

2.8 Analysis

The study used a mixed design with between-subject and repeated measures. It contained two independent conditions: signage relevant to the task (experimental), and no signage (control). Repeated measures within conditions were used: participants first completed baseline measures of attitudes and anxiety towards robots, and again after the robot interaction scenario.

3 Results

3.1 Group differences

A preliminary check using an independent t-test was run to examine pre-trial distribution of participants across two participant groups (experimental and baseline control) and showed no significant differences between experimental and control groups ($t(37) \leq 1.44$, $p \geq .159$).

As a second control measure, gaze duration towards where the signage would/would not be presented (measured in number of frames) was recorded. This control measure was taken to verify that computer monitor was not a distractor in itself and that that experimental group participants were looking at the signs. Results showed that the experimental group participants had a significantly longer gaze duration compared to control group participants ($t(22.94) = -3.93$, $p = .001$). A further measure of signage recollection showed that participants had seen the signs (with 80% accuracy in indicating which signs they have seen) while control group participants indicated that they had not seen any signage.

3.2 Dynamic graphical signage effects on performance

An investigation of task completion accuracy between experimental and baseline control groups with ANOVA (dependent variable accuracy rate, independent variable – condition) showed that overall participants performance was not significantly different between the groups ($F(1, 35) = .45$, $p = .505$).

To investigate whether response time was affected by signage, Linear mixed models (between-subject - condition, within-subject– trial number (1-6), covariate - tube position) was performed on participants' response time on successfully completed trials. The analysis showed a significant main effect of condition ($F(1, 179) = 10.28$, $p = .002$) and main effect of trial ($F(5, 132) = 2.65$, $p = .025$) as well as significant Condition by Trial interaction ($F(5, 132) = 2.34$, $p = .045$; Fig. 3 A).

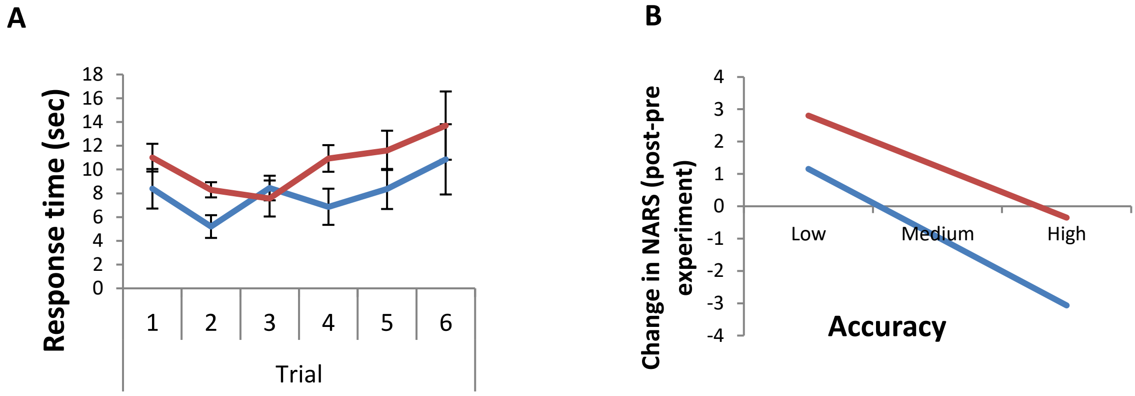

Fig. 3. (A) Response time as a function of task trial in experimental and control groups; (B) Change in NARS score (post-pre-experiment) as a function of task accuracy modulated by participant group. Red line – control group, blue line - experimental group participants.

3.3 Robot Anxiety and Negative Attitudes towards Robots

A moderated regression with independent variable of accuracy, moderator of group (experimental and baseline control), and dependent variables of change between post- and pre-experiment RAS and NARS (two separate models), was done using PROCESS syntax.

The analysis showed that accuracy on the task predicts the change of negative attitudes towards robots moderated by condition ($F(4, 33) = 3.29$, $p = .0226$, $R^2 = 0.29$, Fig. 3 B). The post-trial NARS score decreased compared to the pre-trial NARS score as task accuracy increased, yet this was significant only in the experimental group ($b = -11.28$, $t = -2.66$, $p = .0119$,), but not the control group ($b = -8.43$, $t = -1.89$, $p = .0671$).

No other models were significant either with NARS and predictor response time, or equivalent analysis with RAS ($F(4, 33) \leq 0.341$, $p \geq .796$, $R^2 \leq 0.17$).

4 Discussion

This project explored the effect dynamic graphical signage has on participant's performance, negative attitudes, and robot anxiety on a manufacturing-type HRI task [26]. It was found that showing dynamic signage reduced the response time for completing each trial of the task as well as the decrease in the negative attitudes towards robot after the experiment with increasing accuracy compared to control group with no signage with low skilled manufacturing participants with no prior experience with robots.

These results cannot be explained by group differences as participants' age, computer usage for work and leisure, gaming, NARS, RAS, RTI, programming and robot experience did not significantly differ between groups.

The main finding of the study provides evidence that graphical signage decreases response time. The dynamic signage provided information for the participant about changes in the process, and therefore could help to complete each trial more quickly without needing to unnecessarily adjust the robot position (adding more time for the trial completion). An argument could be made that for collaboration an effective communication is needed, and control group did not receive this communication as they did not have signs. Yet, all the participants collected at least one bolt suggesting that they understood the process enough to partially complete the task while in collaboration with a robot.

Finally, the results showing improved response times are consistent with previous studies showing that with more information about a particular task, individuals' efficiency increases. For example, navigation of unfamiliar settings takes less time with signage [27, 28].

The second aim of the current study was to investigate the effects of signage on participants' negative attitudes towards robots and robot anxiety. The findings revealed a decrease in post-trial negative attitudes towards robots correlating with increasing accuracy, but this decrease was significant only for the experimental group participants. A possible explanation for this result is that participants' sense of empowerment and knowledge of the processes they are going through has increased. Graphical signage is designed to help people understand the requirements of unfamiliar situations, and this information can lead to greater empowerment and a sense of control [6], and decrease the levels of stress experienced [5, 7, 8]. Additionally, negative attitudes towards robots decrease after having interacted with robot [29], and having information about robot abilities and manoeuvrability might have influenced participants' expectations of robot performance [30].

Future directions and implications

The current study results are promising and future studies could take few different developments. First of all, although the signs in this study are not intuitive and participants were not trained nor had similar signs in the factory, but signs reinforced their decisions on how to operate robot once they started the experiment. Therefore, future developments could look into refining signs further to make them more intuitive and clear. At the same time, longitudinal study is needed to fully explore the effects of the signage; investigating the performance after participants became confident in the robotic system would provide further evidence how dynamic signage can aid human-robot collaboration. Finally, although beyond the score of the current study, future experiments could also look into comparing graphical signage versus voice control or text instructions. Comparing the effects of different modalities of information communication would allow determining their drawbacks and strengths, and providing some guidelines for conditions necessary to benefit human and industry the most.

To summarise, this study confirms and extends the results from our previous study by progressing from static to dynamic signage [20, 26]. Dynamic screen-based signage, which is presented at a specific time of relevancy, has been shown to decrease task completion time compared to the no-signage condition. Furthermore, the experimental group's negative attitudes towards robots significantly decreased in correlation with increasing accuracy on the task. Taken together, these results indicate that graphical signage can not only improve efficiency on the task, but also improve participant's comfort when compared to participants receiving no signage.

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