It's All in Your Head: using priming to shape an operator's perceptions and behavior during teleoperation

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ABSTRACT

Perceptions of a technology can shape the way the technology is used and adopted. Thus, in teleoperation, it is important to understand how a teleoperator's perceptions of a robot can be shaped, and whether those perceptions can impact how people drive robots. Priming, evoking activity in a person by exposing them to learned stimuli, is one way of shaping someone's perception. We investigate priming an operator's impression of a robot's physical capabilities in order to impact their perception of the robot and teleoperation behavior; that is, we examine if we can change operator driving behavior simply by making them believe that a robot is dangerous or safe, fast or slow, etc., without actually changing robot capability. Our results show that priming (with no change to robot behavior or capability) can impact operator perception of the robot, their teleoperation experience, and in some cases may impact teleoperation performance.

CCS CONCEPTS

Human-centered computing → Interaction design → Empirical studies in interaction design

KEYWORDS

Teleoperation, human-robot interaction, priming, user experience

1 INTRODUCTION

Robot teleoperation is increasingly used in disaster recovery situations, urban search and rescue, and industrial inspection tasks. Further, recent commercial telepresence robots have made teleoperation more available to non-specialists, and are used to attend remote work meetings, international conferences, and even for remote tourism. However, remotely navigating a robot safely is challenging, as the operator typically relies on a limited interface to maintain awareness of the remote environment [10,37,47]. In fact, research suggests that operation mistakes and errors, such as collisions with people or objects, are commonly due to operator error [16,46]. The operator's opinions and perceptions of a robot, can heavily influence use patterns and ultimate product success [4,27,31,49], thus, designing a robot to feel safer or more usable may affect operation strategy, or operator psychology (e.g., frustration, confidence). Further, prior research in the related area of motor vehicle driving suggests that people may drive differently based on perceived risk of the driving task [15], or drive more recklessly if they believe their vehicle is safer (e.g., because of anti-lock brakes) [23].

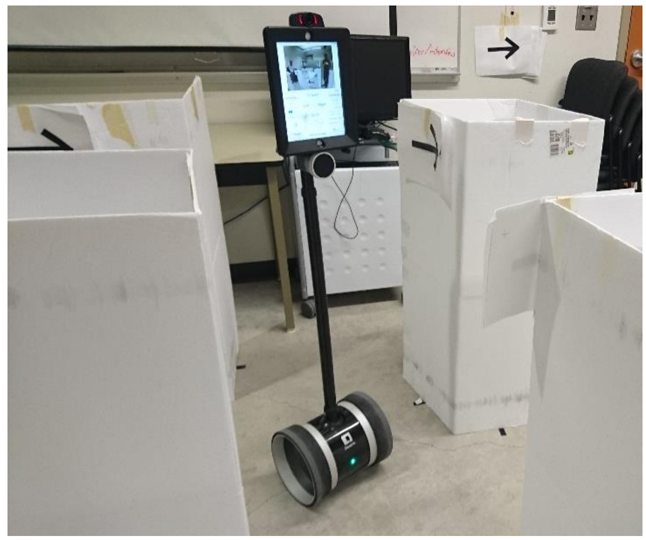

Figure 1. A robot is driven through the obstacle course. We *primed* operators to believe that they were driving robots with different capabilities and potential risks. However, the robot secretly never changed. We examined how priming changes teleoperation behavior and perception of robots.

In this work, we explore the feasibility of shaping operator perception of the robots they are operating by priming them about the robot's capabilities, and further investigate the priming's impact on operation behavior. Specifically, we explore whether we can influence, or *prime*, an operator's perception of the riskiness of driving a robot (e.g., if it is faster, more powerful, or less stable), and whether this may encourage a change in the operator's driving behavior.

We take two approaches to priming operators: we prime their perception of a robot through a) verbal and visual description of

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robot capability, and b) tangible priming of robot capability by static joystick stiffness. In both cases, our goal is to prime operators to believe that a robot is more or less safe. For each approach, we conducted a study where participants believed they were operating different robots; in reality, they operated the same robot multiple times, and were only subjected to different priming stimuli. We investigated whether the priming was successful in impacting operator perception of the robot, and whether the priming impacted teleoperation performance.

Our study results suggest that priming can be effective for shaping operator perceptions of robots: in both studies operators believed that the (identical) robots were had different capabilities, even after multiple navigation tasks. Further, we found our tangible priming method may impact teleoperation performance and self-reported task load, although further inquiry is required to confidently make this claim. Our results serve as proofs of concept for using priming to impact teleoperator perceptions of a robot and their driving behavior, without making any changes to robot capability. Given evidence that perceptual change can be important for safety (e.g., leading to different driving speeds [9]), use, and adoption [27,31,49], our results highlight the feasibility of exploring priming for improved teleoperation. We envision that further exploration and application of priming can be a new HRI design avenue for improving teleoperation and promoting safe operator driving behavior.

2 BACKGROUND: PRIMING

In psychology, *priming* is a widely studied topic across a range of applications and methods that uses a stimulus (the priming) to cause an impact on an event or interaction. In our work, we focus on *behavioral priming*, where exposing a person to a stimulus or concept elicits some associated knowledge from previous experience, and impacts their behavior based on that experience [4,12,13]. In this case, priming can often induce a behavior change, without the person being aware of the priming [1,4,12,24]; however, priming can still be effective even if the person becomes aware of priming [13]. Priming is not limited to being performed beforehand, but is considered to occur as long as the priming features are present (e.g. a constant priming stimulus) [2,4].

A very broad range of priming methods have been researched in psychology. Many of these are indirect and can be very subtle, such as omitting a word in a sentence [4], showing a picture of a situation to encourage the associated behavior (e.g., showing a picture of a library to make people quieter) [1,12], or playing musical chords to affect word choice [41]. Priming can also be metaphoric with tangible sensations, such as a person being seen as more important when holding a heavier clipboard [2]. More explicit examples include describing a person as mean or kind to prime others, which increases the likelihood that the primed people will see those qualities once they meet the person described [24]. This body of work demonstrates how priming can be used practically to alter and shape a person's perceptions and behavior.

Measuring the causes and effects priming has been shown to be difficult [13,45], in part because priming effects can be highly context sensitive [1,4,13,28]. For example, priming effects can vary due to the environment (e.g., sounds [41]), or nuances of the task description [28]. As such, inquiry into priming in teleoperation will require a range of studies and variants, and replication work, to get a complete picture. This motivates our decision to test two priming methods in our work.

Although the effectiveness of priming is established in some domains, the science is still unclear on the limits and applications of priming [13]. We build on the work of behavioral priming in psychology by extending it to explore the use of priming for shaping teleoperator perception of their robot, and their behavior.

3 RELATED WORK

A core area of research in teleoperation aims to improve operator performance, including faster task completion time, fewer critical incidents such as collisions, and lower perceived workload [9]. General approaches include modifying on-screen information displays to aid an operator's understanding of the robot and its surroundings (e.g., [22,25,32,37,39,47]), or designing new ways to physically control the robot (e.g., [35,38,50]). These works aim to improve teleoperator performance by improving the operator's controls or ability to understand and correctly react to a situation. Our work is complementary to this method, where we aim to explore teleoperator performance after priming their perception of the robot.

Psychological aspects of driving motor vehicles, such as the perception of a vehicle's capabilities and its surroundings, have been shown to change driving behavior [17,18]. People may change their driving behavior based on the perceived risk of the surrounding environment [30], vehicle type [14], and driver mood [34]. Vehicle controls, such as haptic accelerator pedals [29], or transmission choice [7] can also affect driving psychology. We extend this research in vehicle control to robot teleoperation, investigating how to prime different perceptions of the robot, and if the priming affects teleoperation performance.

Research has investigated using psychology-based designs in software to influence behavior. For example, attention and perception literature has been used to generate new teleoperation interfaces to improve teleoperation performance in visual search tasks [37,44,48]. Other aspects of software use, such as engagement with, and motivation to use software has been improved with the use game-based techniques (gamification) [3,20,26]. Some research has even used priming, for example by showing how priming users can affect their experience in virtual environments [33]. We follow this line of research by investigating priming teleoperator perceptions of a robot's capabilities, and observing how it may affect operator behavior, and perception of the robot.

Social HRI has explored the use of priming, or a variant called framing [45] in social interactions between people and social robots. Multiple approaches employing subtle shifts in language while talking about robots have influenced how personally [11] or human-like [42] people view or treat the robot. People will even subconsciously imitate robot speech patterns when interacting with a robot [8], an effect called lexical entrainment that shares similarities to priming. Priming can also make people believe an autonomous robot is actually teleoperated [43]. Experimental challenges have been noted for HRI, in that priming effects can be very sensitive to types of stimuli used for priming or the surrounding context of the priming environment, and that detecting changes can be difficult [45]. We complement this body of work by investigating the impact of priming methods in teleoperation.

Others have attempted to change an operator's perception of a robot to shape their teleoperation behavior; while not presented as priming per se, these works use stimuli to evoke feelings and change behavior. For example, it has been shown that robot designers can physically change a robot's driving feel to impact the operator's mental workload and performance [36], or make operators feel safer [5]. Dynamic haptic feedback mechanisms that react to the robot's changing environment can also influence the operator to better avoid obstacles [19]. These works demonstrate that there are numerous approaches to how we can mentally influence teleoperators. We complement the research by investigating how to shape perceptions about a robot's physical abilities with no actual modification to robot behavior or any additional real-time feedback during interaction; we shape perceptions only through descriptions or static joystick stiffness.

4 TELEOPERATOR PRIMING TECHNIQUES

Based on our background research outlined in Section 2, we explore two priming techniques not previously explored in the literature: visual and textual robot description, and tangible joystick stiffness, to represent robot capability. We applied both of these to the Double 2 telepresence robot (see Figure 1). We were not able to find examples of these methods in the priming literature.

In both cases, the goal of our priming was to instill beliefs into the operator about how safe, or unsafe, the robot is. This builds on prior research suggesting how perceptions of safety may impact driving behavior [17,18]. We carefully crafted our priming stimuli with this in mind. In each method, we developed three levels of the priming on a continuum: one to represent a robot as more dangerous, one to represent a safer robot, and one in the middle of the two. In all cases, the same robot was used, and it reacted and responded identically to the same input – only the priming changed.

4.1 Tangible Priming

We used constant tangible joystick stiffness to prime people about a robot's capabilities by changing the static stiffness of a joystick between robots (Figure 2). An object's tangible weight has been found to change how people who hold them are perceived [2], thus we investigate the perceptual effects of the weight of a joystick on teleoperation. There was no real-time adjustment of the stiffness (i.e., no live feedback): the virtual spring settings (that simulate the feel of a classic spring-based joystick) were held constant during control of a robot, and settings were only changed between conditions to represent stronger or weaker springs. Participants were told the joystick may feel different with each robot based on robot capabilities. The robot itself and joystick behavior never changed – a given joystick position would result in identical behavior regardless of spring settings.

Figure 2. The joystick we used for tangible priming – Microsoft Sidewinder Force Feedback 2 USB joystick.

The design intention was for stronger spring stiffness, which resists manipulation, to imply a slower or heavier robot – and thus be safer to drive. With lighter spring stiffness, the intention was for the robot to feel more responsive, like a light, "zippy" vehicle that quickly accelerated – thus being less safe to drive.

We had three levels: safe robot (100% of device maximum spring and friction stiffness), unsafe robot (10% spring and friction stiffness), and middle robot (50% spring and friction stiffness). People were not told about the intended three safety levels, but were instead told that "Each robot will interact with the joystick differently, based on the robot's physical design."

4.2 Descriptive Priming

We used a description of the robot being operated to prime people about the robot's capabilities, employing both verbal description and visual aids that represent different robot characteristics. As in the prior condition, the robot itself never changed.

We designed three priming variants to match our safe, unsafe, and middle designs. For each variant, we crafted a fake robot model and simple specification sheet (Figure 3), and we used a scripted explanation when introducing the robot that emphasized the safety and risks of each. The robot characteristics included motor power, balance, and traction, characteristics designed to prime people on the robot's safety of operation. People kept the specification sheet in front of them during operation.

The "Double Turbo" model (Figure 3c) was designed to appear as a fast and dangerous robot, and was introduced as a design that was "made to prioritize speed over all else." The "Double Tuff" model (Figure 3a) was designed to appear safe to operate, and was introduced as a design that was "made to prioritize robustness and product life." The "Double Home" (Figure 3b) was designed to appear as a balanced robot, and was introduced as a design that "focused on balance and battery life, but is easier to break."

5 INVESTIGATING PRIMING IN TELEOPERATION

We conducted two within-participants studies to investigate the impact of each of our two priming methods on teleoperation; in particular, we investigated persistent teleoperator perception of a

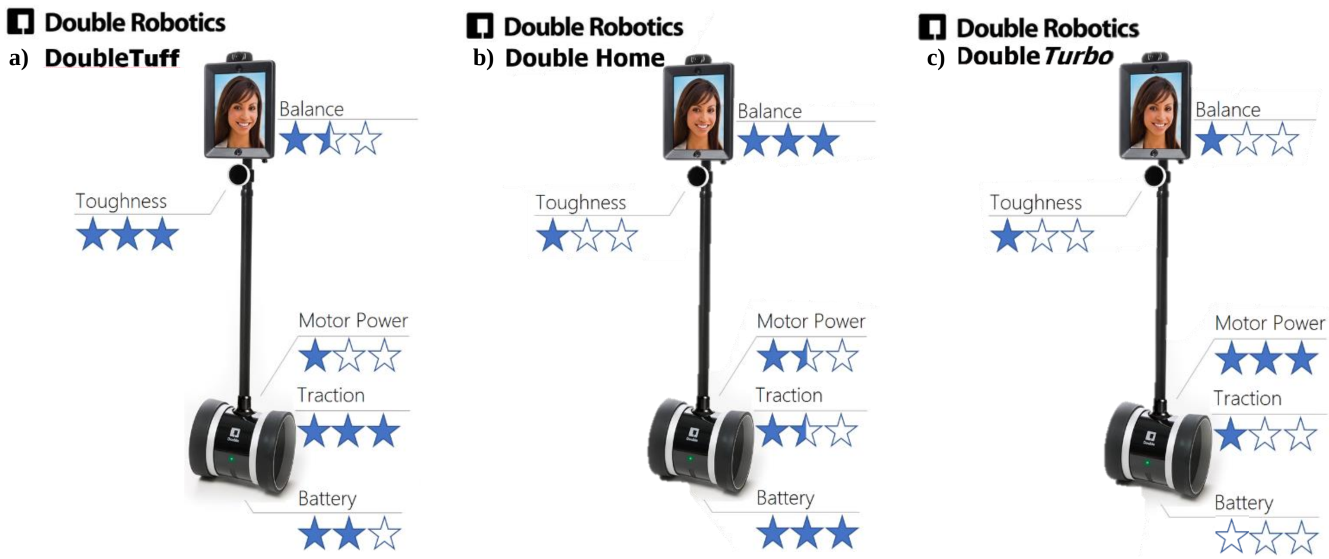

Figure 3. The priming sheets were explained and given to participants before the study. The sheet of the robot being driven was left on the desk for participant's reference. a) the safe condition b) the middle condition c) the unsafe condition

robot after operating it, and teleoperation performance. These studies were nearly identical, with the primary difference being the priming employed.

5.1 Instruments

Participants controlled a Double 2 telepresence robot over our university's Wi-Fi network, using the official Double wide-angle camera (150 degree field of view) and HD audio (speaker and microphone) kits. The camera feed and joystick networking was managed by custom software running on the Double's iPad Air 2. The robot was controlled by a Microsoft Sidewinder USB Force Feedback 2 joystick.

Participants viewed the robot's full-screen camera feed on a 24 inch IPS monitor. The resolution of the feed was 640 by 480 pixels, compressed using MJPEG (iOS JPEG library, 50% compression). Our setup maintained a steady framerate of 15 frames per second. Participants wore headphones so they could hear the robot sounds from the remote location.

Participants completed questionnaires on the same machine but on a separate monitor, using Google Forms, with a final free-form questionnaire completed on paper.

5.2 Task

Participants were tasked with navigating the robot through an obstacle course. They were instructed to drive and complete the task as quickly as they felt comfortable, while trying to avoid colliding with obstacles, walls, etc.; we emphasized to participants that it was not a race, but we were recording their completion times. While the room and obstacle configuration remained static, we designed three different (but roughly equivalent difficulty) paths through the course for use in a counterbalanced within-participant design. (Figure 1, Figure 4). Each path had the same Manhattan distance and number of turns, and took approximately 2~5 minutes per lap, depending on driving speed and number of collisions.

The paths were designed to be long enough to provide opportunities for different driving styles (tight navigation, long stretches, etc.). The obstacles were desks and large cardboard pieces that generated loud noises (audible to the operator) when the robot collided with them.

5.3 Measurements

Our performance measurements were selected as simple operation measures used in prior work [9,36], and subjective reflection based on priming goals (perception of performance-related variables). We recorded the time participants took to complete laps of the obstacle course, and the number of collisions with obstacles, walls, etc. A collision was defined as any time the robot touched an object in the room – magnitude of the collisions was not considered.

After completing the task for a condition, participants filled out self-report questionnaires to gauge their subjective workload (via NASA TLX [21]), perceptions of the robot, and the teleoperation experience. The latter included 5-point Likert-like scale items inquiring about perceived speed, weight, steering, durability, power, safety, and responsiveness of the robot.

Participants also completed free-form written questions inquiring about their experience, after each condition. These questions were optional, and asked participants for any positive, negative, or other feedback they wished to provide us about the robot and teleoperation experience. We collected demographics information at the beginning of the experiment as well, including age, gender, frequency of playing video games, frequency of driving, and self-reported driving skill.

5.4 Procedure

The same procedure was followed for both of the priming studies, with differences highlighted in the corresponding sections below. Participants were first given a briefing of the experiment and signed an informed consent form. Participants were told that they will test

3 new prototype telepresence robots in order to help us evaluate the safety and drivability of each robot for new users. We described the robots as being similar in size and shape, but with different internal components that may change how they perform. We explained the overall procedure of the experiment, and introduce the joystick and obstacle course that they will use. Further, before starting, we explained either the connection between the robot and joystick (for the tangible priming) or the robot data sheets (for the descriptive priming). The participants were seated in a room removed from the actual room with the robot and obstacle course in it.

Following the introduction, a priming condition was applied and the participant teleoperated the robot through the obstacle course. We asked them to complete three laps of the course, after which we administered the post-condition questionnaire to elicit their impressions of the robot and teleoperation experience. The participants were instructed the first lap was a learning trial. We only recorded time and collision data for the second and third laps. This was repeated for the three priming conditions (safe, middle, unsafe), with the order of the priming conditions and the path through the course (Figure 4) fully counterbalanced.

Finally, after all three conditions, the participants were debriefed about the deception in the obstacle course room with the robot – it was, in fact, always the exact same robot. The experiment was then re-explained in the context of the deception and how the deception helps achieve the research goal. The participants were then encouraged to engage with a discussion with the researcher about the experiment.

Our university's research ethics board approved both studies.

5.5 Study 1: Tangible Priming

We recruited 25 participants. One did not complete the experiment, and two others were identified as outliers: we observed them not attempting to avoid obstacles (e.g., laughing and pushing obstacles around), and this was reinforced from their data (>1.5 Inter-quartile range). This resulted in 22 participants (mean age of 24, standard deviation of 6.3 years; 12 female).

5.5.1 Results

To investigate whether the tangible priming worked, we conducted Friedman's ANOVA tests on our Likert-like scale perception data. We found statistically significant results for perceived speed, perceived steering ability, perceived durability, and perceived safety (see Table 1). Other tests on perceived teleoperation experience were non-significant. Further, we found no effect of variables from the demographics questionnaire (video game, driving experience).

Both completion time and number of collisions were right skewed (non-normal, Shapiro-Wilk test, p<.05), and were corrected using a square root transform.

To investigate teleoperation performance, we performed repeated measures ANOVAs on completion time, collisions, and perceived workload. We found a statistically significant, effect of tangible priming condition on collisions ($F_{2,42}$=5.2, p=.01, η^2=.20, Figure 5). Post-hoc tests (Bonferroni familywise correction) found the safe condition to have on average 4.8 fewer collisions (42% fewer) than the unsafe condition (p=.001, 95% confidence interval of the mean difference [1.8 collisions, 7.8 collisions]).

We further found a statistically significant effect of tangible priming on perceived workload (NASA TLX sum, $F_{2,42}$=3.6, p<.04, η^2=.14, Figure 6). Post-hoc tests (Bonferroni familywise correction) found the non-safe condition to have on average 5.0 points higher (14% higher) perceived workload than the safe condition (p<.04, 95% confidence interval of the mean difference [.22 TLX points, 9.7 points]).

5.5.2 Discussion of Tangible Priming

Our results indicate that our tangible priming conditions caused participants to perceive the robot and teleoperation experience differently: we found differences in perceived safety, durability, steering ability, and speed. Further, these differences aligned with the expected impact of the priming. Given that the robot reacted and responded identically in all conditions, and participants spent time controlling the robot, it would be reasonable to expect participants to rate the robots based on how it actually performed,

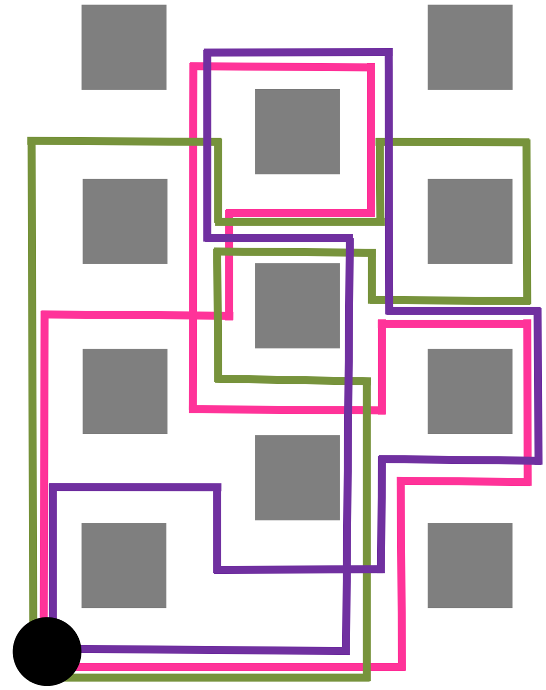

Figure 4. The room and obstacle layout used in the study design, with the three paths through it.

Table 1. Mean ranks and chi-square values for perceptual effects for tangible priming. All listed values are *p*<.05. Omitted tests are n.s.

	unsafe	middle	safe	$\chi^2(2)$
speed	2	2.4	1.7	7.0
steering	1.6	2.2	2.2	6.6
durability	1.7	2	2.3	6.9
safety	1.7	2	2.3	8.0

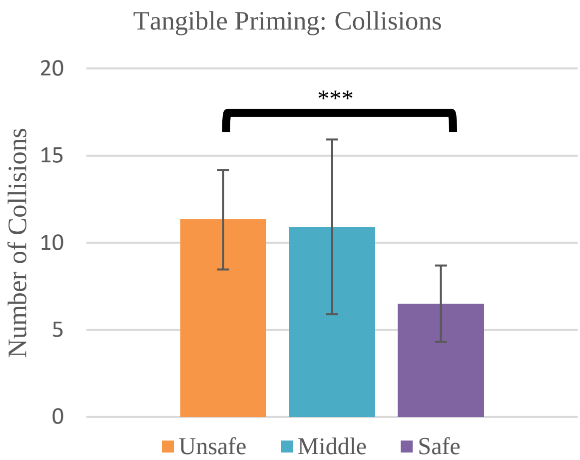

Figure 5. Average collisions per condition. ****p*<.001. Error bars show 95% confidence interval.

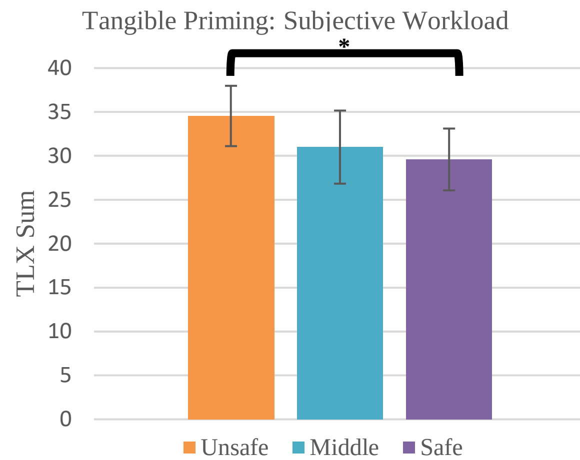

Figure 6. Average TLX sum score per condition. **p*<.05. Error bars show 95% confidence interval.

and perhaps notice that the robots were the same (or only slightly different). However, the fact that participants rated the robots differently despite this is a clear indication that the tangible priming method worked to shape participant perception of the robot and teleoperation experience.

We further found a significant difference in collisions, with the non-safe condition having a 42% reduction (average 11.4 in the unsafe, and 6.6 in the safe), and participants reported lower task load with the safe condition (average 5.0 TLX points, 14%, lower than the unsafe condition). We note, however, a potential confound in the study: the *usability* of the different stiffness settings may explain the performance difference (e.g. the stiffer joystick was easier to use than the loose setting). Additional inquiry is required to analyze this further.

Looking at our performance and perception results together, we see that people drove the safe condition in a safer manner. This is counter to our prediction from related work that suggested people may drive a safer robot more recklessly. Regardless, our priming method was a success, considering the changes in perception (e.g., of speed or steering capabilities) even though participants drove an identical robot each time. We conclude that the physical properties of an input method can be used to prime users and change their perceptions of the robot, and may also impact their performance.

5.6 Study 2: Descriptive Priming

We recruited 24 participants (none participated in the Tangible Priming study); three were removed as outliers as they did not attempt to avoid obstacles (e.g. driving full speed and not stopping for any obstacle), or did not appear to understand the instructions (e.g., frequently took wrong turns in the obstacle course). This was reinforced as outliers in the data (>1.5 Inter-quartile range). This resulted in 22 participants (mean age 24, SD 6.3 years; 12 female).

The priming specification sheets (Figure 3) were explained in detail to participants at the introduction of the study, and the sheet associated with each condition was left with the participant during the task. Participants were given time to review the specification sheet (the priming) before each condition, and the sheets were removed during the post-condition questionnaire.

To further reduce potential learning effects (in addition to the counterbalancing) we added an additional training step after the initial explanation, and before the first condition: participants practiced using an additional, similar path through the obstacle course for two laps. Participants were told they were piloting the current commercially available robot model (compared to the "prototypes" that followed).

Additional self-report measurements were added post-experiment to reflect the particular details of our priming. Participants rated the robots on the criteria we used in the priming specification sheets (Figure 3). Participants were specifically asked to report based on their teleoperation experience, not on their memory of the specification sheets.

5.6.1 Results

To investigate whether the priming worked, we conducted Friedman's ANOVA tests on our post-condition Likert-like scale data. We found statistically significant results for perceived speed, perceived steering ability, perceived durability, and perceived safety (see Table 2). Other tests on perceived teleoperation

Table 2. Mean ranks and chi-square values for perceptual effects for descriptive priming. **p*<.10, all other listed values are *p*<.05. Omitted tests are n.s.

	unsafe	middle	safe	$\chi^2(2)$
speed	2.5	1.5	1.9	8.6
weight	1.6	2.1	2.3	6.5
power	2.4	1.7	1.9	7.5
safety	1.6	2.3	2.1	8.3
balance	1.6	2.5	1.9	12.7
motor power	2.4	1.6	2.0	7.4
toughness*	1.7	2.0	2.3	4.6
traction*	1.6	2.1	2.2	4.9

experience were non-significant. Friedman's ANOVA tests on the post-experiment specification sheets found statistically significant results for balance and motor power, with trends for toughness and traction. These results are also included in Table 2.

Repeated measures ANOVAs found no significant results on completion time (means for not safe=165s, middle=176s, safe=171s), collisions (means for not safe=6.0 collisions, middle = 5.4 collisions, safe=5.8 collisions), and perceived workload (means for not safe=29.4 points, middle=29.4 points, safe=27.7 points).

5.6.2 Qualitative results

Given the lack of impact of description priming on teleoperator performance, we performed post-hoc open-coding qualitative analysis on participant short-form responses. This was done to better understand the impact of our priming on participants' teleoperation experiences and perceptions of the robot.

We found that 20 participants (83%) made explicit comparisons between the robots capabilities and their teleoperation experiences with them:

> I love the response time and the power of the [unsafe condition]. It's quicker than the [safe condition] and I felt like the wind. – p33

> I felt more in control with [the safe condition] – p43

> Aside from durability, everything else about [the middle condition] felt more stable – p38

These comments covered a range of aspects of teleoperation that were in fact consistent across robot conditions. Further, these comments aligned well with the primed robot characteristics, and were not randomly associated.

All 8 participants who mentioned speed wrote that the unsafe condition was faster than other robots:

> It's quicker than the previous robot and I felt like the wind – p33

> It was hard to keep the balance on this robot as it was light and had more speed. – p40

Speed was less commonly mentioned in the other conditions (3 times total), which were characterized as slower:

> [The middle condition] didn't accelerate as fast as the other robots – p26

Control was another common theme, where six people reported the safe condition having better control:

> I liked how in control I felt of the steering and acceleration. There were no surprises. – p35

with only one to the contrary. In contrast, three people mentioned the middle condition had better control than the unsafe condition, and 2 mentioned that the unsafe condition had worse control overall.

Finally, "responsiveness" was another common theme. The unsafe robot was most commonly discussed, with 7 participants commenting on the theme all saying that it was more responsive, for example, "It responds quickly, and seemed to navigate at relatively high speed." – p37. The 4 participants who mentioned responsiveness with the middle robot all had similar comments to "the robot felt more flimsy and unresponsive" – p35. Only 2 participants mentioned the responsiveness of the safe condition: one participant mentioned it was "more responsive" – p46, while the other disagreed:

> The robot is slower, doesn't have a faster response rate, motor power is definitely weak. My head is hurting trying to operate this robot. – p33

5.6.3 Discussion of Descriptive Priming

In this experiment, we investigated the impact of priming teleoperation operators using a visual and verbal description of the robot. Our results suggest that description priming (using paper and speech only) successfully changed participant perception of the robot, and their experience teleoperating it: we successfully altered participant perception of robot speed, weight, power, and overall safety. Further, our post-test questionnaire results indicated that our non-safe condition was successfully primed to be riskier than our safe condition in terms of balance and motor power, with trends pointing to potential priming in toughness and traction. These results emerged in spite of participants driving the exact same robot in each condition.

Our qualitative results further supported this, and highlighted the effectiveness of our priming. More than simply memorizing the details provided to them, the conviction and strong tone in the written feedback suggests that the participants believed that the differences were real, despite having operated the exact same robot through a task repeatedly.

We did not find any performance change in terms of completion time, collisions, or perceived workload. It is possible there is still a small effect that went undiscovered due to our small sample size of 22 (after outlier removal). If there is indeed no effect on performance, it will be important to further investigate how this disparity between perceptions and performance can happen, and what it means for long-term use. Importantly, our results suggest that we can improve user perception of the safety or physical capabilities of the robot without sacrificing performance or changing functional aspects of the design.

6 DISCUSSION AND LIMITATIONS

In both studies, our priming methods shaped perceptions of the robot and convinced participants that the robots were different, despite driving the identical robots for upwards of 30 minutes; given that, in all cases, the robot was identical and did not change, one would reasonably expect participants to drive approximately equivalently, to rate the robots similarly, and to realize that they are the same or very similar despite what we told them. That we found differences in all the above measures reflects the potential of priming, and its potential in teleoperation. Leveraging perceptual changes could be immediately impact teleoperation, as perceptions of a product and its quality can heavily influence product success and use patterns [4,27,31,49]. Designing robots to *feel* safer or more usable can affect use, adoption, and popularity.

While both priming methods were successful in changing participant perceptions of the robot and teleoperation experience, we only found teleoperation performance changes with the tangible method. While this result is promising, resulting in fewer collisions and lower workload, further inquiry is required to understand how much of this change was due to the priming, and how much due to the usability of the joystick stiffness. Clarifying this confound, exploring other descriptive priming methods, and exploring other performance metrics (e.g. average robot velocity), will help us better understand the limits and potential of priming on teleoperation performance. Regardless, as perceptions of technology can affect user experiences and influence adoption and acceptance of technology [4,27,31,49], even without performance differences, priming can be an important tool for roboticists in shaping how their robots are perceived and accepted.

This work assumes that people respond in the same way to priming stimuli. However, it could be that different personalities may be more prone to risk taking, as suggested in transportation research [23]. In our results, our *safe* condition primed *safe* behavior, while some previous research suggests that the inverse may be true; for example, adding safety features to cars may result in less safe driving [23]. In teleoperation, a fast robot may encourage safer driving behaviour from a cautious person, or a thrill-seeking operator may get excited and try push the robot to its limits. We note that the science surrounding priming is still has conflicting results [13], thus we recommend further inquiry into priming and teleoperation, considering a participant's risk-tolerance.

Our scenario also limits the generalizability of our results. The obstacle course was designed to imitate a very crowded office or conference venue and make teleoperation difficult. However, environments with dynamic obstacles (such as people in a busy subway station), or wider spaces such as many museums may change the teleoperation experience. As we noted earlier that research suggests that context is important for priming effects, investigating context for teleoperation and priming is an important consideration.

7 FUTURE WORK

These results serve as an initial starting point for looking at priming for teleoperation. Even our two priming method labels – descriptive and tangible – are general and can be explored much further and much more deeply. For example, descriptive research may look at priming with actual demonstrations of robot behavior (using acting to prime the danger or ease of teleoperation), different robot morphologies, or different robot sounds. Similarly, additional tangible methods could control force feedback effects to make collisions seem larger by adding kickback when a robot collides with something. Exploring each technique in depth, and starting to explore a broader range of priming techniques, is important for understanding the nuances of how priming can affect teleoperation.

We should also explore priming beyond portraying the robot as more or less safe. For example, sound could be used to represent environmental danger in real time, or we could explore whether the enjoyment of teleoperating the robot could be primed. This is a new avenue to consider for teleoperation robot and interface design, and leads to a broad range of future work.

Priming effects are often studied in the short term, such as our work in this paper. Long term effects of priming are less studied, and thus should be studied in the context of teleoperation; prior work suggests priming may last for hours or even months, even if new experiences contradict the priming [6,27,40]. Perhaps short-term priming effects, especially when operators are first learning to drive a robot, may influence the development of safe long-term habits, but this must be formally studied. Such research would benefit both the psychology and teleoperation communities.

8 CONCLUSIONS

This work serves as a proof of concept for using behavior priming to shape a teleoperator's perception of a robot, their experience teleoperating it, and possibly their teleoperation performance. This work takes priming, which has been used and studied extensively in psychology, and presents it as a concrete and practical tool to be used by robot teleoperation designers.

We explored two specific priming approaches: one primes an operator's impressions by describing a robot's capabilities with a visual and vocal explanation; the other approach primes the operator with a tangible stimulus to represent robot capability. Our results demonstrate how priming can be successfully used to change operators' perceptions of a robot's speed, safety, power, and weight, and in some cases may even change their teleoperation performance in terms of number of collisions, and perception of workload, although further inquiry is needed to clarify the source of these performance differences (priming or joystick usability). These changes occur without ever changing the robot, its programming or behavior, or on-screen interface.

Interface and robot design continue as important challenges to improve teleoperation, as both are important for usability and user experience. We believe that this work on priming teleoperators provides HRI designers with an additional tool to further shape teleoperation performance and user experience.

REFERENCES

1. Henk Aarts and Ap Dijksterhuis. 2003. The silence of the library: Environment, situational norm, and social behavior. *Journal of Personality and Social Psychology* 84, 1: 18–28.

2. Joshua M Ackerman, Christopher C Nocera, and John a Bargh. 2010. Incidental Haptic Sensations Influence Social Judgments and Decisions. *Science* 328, 5986: 1712–1715.

3. Judd Antin and Ef Churchill. 2011. Badges in social media: A social psychological perspective. In *CHI*, 1–4.

4. John A. Bargh, Mark Chen, and Lara Burrows. 1996. Automaticity of social behavior: Direct effects of trait construct and stereotype activation on action. *Journal of Personality and Social Psychology* 71, 2: 230–244.

5. Chandrayee Basu, Qian Yang, David Hungerman, Mukesh Singhal, and Anca D. Dragan. 2017. Do You Want Your Autonomous Car To Drive Like You? In *Human-Robot Interaction*, 417–425.

6. Suzanna Becker, Morris Moscovitch, Marlene Behrmann, and Steve Joordens. 1997. Long-term semantic priming: A computational account and empirical evidence. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 23, 5: 1059–1082.

7. Mike Blommer, Reates Curry, Radhakrishnan Swaminathan, Louis Tijerina, Walter Talamonti, and Dev Kochhar. 2017. Driver brake vs. steer response to sudden forward collision scenario in manual and automated driving modes. *Transportation Research Part F: Traffic Psychology and Behaviour* 45: 93–101.

8. Jürgen Brandstetter, Clayton Beckner, Eduardo Benítez Sandoval, and Christoph Bartneck. 2017. Persistent Lexical Entrainment in HRI. In *Human-*

Robot Interaction, 63–72.

9. Jessie Y. C. Chen, Ellen C. Haas, and Michael J. Barnes. 2007. Human Performance Issues and User Interface Design for Teleoperated Robots. *IEEE Transactions on Systems, Man and Cybernetics, Part C (Applications and Reviews)* 37, 6: 1231–1245.

10. Jessie Y C Chen, Michael J. Barnes, and Michelle Harper-Sciarini. 2011. Supervisory control of multiple robots: Human-performance issues and user-interface design. *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews* 41, 4: 435–454.

11. Mark Coeckelbergh. 2011. Talking to robots: On the linguistic construction of personal human-robot relations. *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST* 59 LNICST: 126–129.

12. a Dijksterhuis and Ja Bargh. 2001. The perception-behavior expressway: Automatic effects of social perception on social behavior. *Advances in experimental social psychology* 33: 1–38.

13. Stéphane Doyen, Olivier Klein, Cora Lise Pichon, and Axel Cleeremans. 2012. Behavioral priming: It's all in the mind, but whose mind? *PLoS ONE* 7, 1.

14. Chloé Eyssartier, Sébastien Meineri, and Nicolas Gueguen. 2017. Motorcyclists' intention to exceed the speed limit on a 90km/h road: Effect of the type of motorcycles. *Transportation Research Part F: Traffic Psychology and Behaviour* 45: 183–193.

15. Ray Fuller. 2005. Towards a general theory of driver behaviour. *Accident Analysis and Prevention* 37, 3: 461–472.

16. Stefanie Giese, David Carr, and Javaan Chahl. 2013. Implications for unmanned systems research of military UAV mishap statistics. *IEEE Intelligent Vehicles Symposium, Proceedings*, Iv: 1191–1196.

17. J.A. Groeger and J.A. Rothengatter. 1998. Traffic psychology and behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour* 1, 1: 1–9.

18. John A. Groeger. 2002. Trafficking in cognition: Applying cognitive psychology to driving. *Transportation Research Part F: Traffic Psychology and Behaviour* 5, 4: 235–248.

19. Akif Hacinecipoglu, E. Ilhan Konukseven, and A. Bugra Koku. 2013. Evaluation of haptic feedback cues on vehicle teleoperation performance in an obstacle avoidance scenario. In *2013 World Haptics Conference, WHC 2013*.

20. Juho Hamari, Jonna Koivisto, and Harri Sarsa. 2014. Does gamification work? - A literature review of empirical studies on gamification. *Proceedings of the Annual Hawaii International Conference on System Sciences*, JANUARY: 3025–3034.

21. Sandra G. Hart and Lowell E. Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Human Mental Worload*. 139–183.

22. Sunao Hashimoto, Akihiko Ishida, Masahiko Inami, and Takeo Igarash. 2011. TouchMe: An Augmented Reality Based Remote Robot Manipulation. *International Conference on Artificial Reality and Telexistence*: 1–6.

23. Brian A. Jonah, Rachel Thiessen, and Elaine Au-Yeung. 2001. Sensation seeking, risky driving and behavioral adaptation. *Accident Analysis and Prevention* 33, 5: 679–684.

24. Harold H Kelley. 1950. The Warm-Cold Variable in First Impressions of Persons. *Journal of Personality* 18, 4: 431–439.

25. a Leeper, Kaijen Hsiao, M Ciocarlie, L Takayama, and D Gossow. 2012. Strategies for human-in-the-loop robotic grasping. *Human-Robot Interaction (HRI), 2012 7th ACM/IEEE International Conference on*: 1–8.

26. Wei Li, Tovi Grossman, and George Fitzmaurice. 2012. GamiCAD: A gamified tutorial system for first time AutoCAD users. *UIST*: 103–112.

27. Gitte Lindgaard, Gary Fernandes, Cathy Dudek, and J. Brown. 2006. Attention web designers: You have 50 milliseconds to make a good first impression! *Behaviour & Information Technology* 25, 2: 115–126.

28. Colin M. MacLeod. 1989. Word context during initial exposure influences degree of priming in word fragment completion. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 15, 3: 398–406.

29. Rich C. McIlroy, Neville A. Stanton, and Louise Godwin. 2017. Good vibrations: Using a haptic accelerator pedal to encourage eco-driving. *Transportation Research Part F: Traffic Psychology and Behaviour* 46: 34–46.

30. John A. Michon. 1985. A critical view of driver behavior models: what do we know, what should we do? *Human behavior and traffic safety*: 485–520.

31. Debanjan Mitra and Peter N. Golder. 2006. How Does Objective Quality Affect Perceived Quality? Short-Term Effects, Long-Term Effects, and Asymmetries. *Marketing Science* 25, 3: 230–247.

32. Curtis W. Nielsen, Michael A. Goodrich, and Robert W. Ricks. 2007. Ecological interfaces for improving mobile robot teleoperation. *IEEE Transactions on Robotics* 23, 5: 927–941.

33. D Nunez and E Blake. 2003. Conceptual Priming as a Determinant of Presence in Virtual Environments. In *Computer Graphics, Virtual Reality and Visualisation in Africa*, 101–108.

34. Lisa Precht, Andreas Keinath, and Josef F. Krems. 2017. Effects of driving anger on driver behavior – Results from naturalistic driving data. *Transportation Research Part F: Traffic Psychology and Behaviour* 45: 75–92.

35. Sina Radmard, Ajung Moon, and Elizabeth A Croft. 2015. Interface Design and Usability Analysis for a Robotic Telepresence Platform. In *RO-MAN*, 6.

36. Daniel J Rea, Mahdi Rahmani Hanzaki, Neil Bruce, and James E Young. 2017. Tortoise and the Hare Robot Slow and steady almost wins the race , but finishes more safely. In *Robot and Human Interactive Communication (RO-MAN)*, 1–6.

37. Daniel J Rea, Stela H Seo, Neil Bruce, and James E Young. 2017. Movers, Shakers, and Those Who Stand Still: Visual Attention-grabbing Techniques in Robot Teleoperation. In *Human-Robot Interaction*, 398–407.

38. Daisuke Sakamoto, Koichiro Honda, Masahiko Inami, and Takeo Igarashi. 2009. Sketch and run: a stroke-based interface for home robots. *Conference on Human Factors in Computing Systems*: 197–200.

39. Ashish Singh, Stela H. Seo, Yasmeen Hashish, Masayuki Nakane, James E. Young, and Andrea Bunt. 2013. An interface for remote robotic manipulator control that reduces task load and fatigue. *RO-MAN*: 738–743.

40. Steven A. Sloman, C. Gordon Hayman, Nobuo Ohta, Janine Law, and et al. 1988. Forgetting in primed fragment completion. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 14, 2: 223–239.

41. Bernhard Sollberger, Rolf Rebe, and Doris Eckstein. 2003. Musical Chords as Affective Priming Context in a Word-Evaluation Task. *Music Perception* 20, 3: 263–282.

42. Anna Stenzel, Eris Chinellato, Maria A. Tirado Bou, Ángel P. del Pobil, Markus Lappe, and Roman Liepelt. 2012. When humanoid robots become human-like interaction partners: Corepresentation of robotic actions. *Journal of Experimental Psychology: Human Perception and Performance* 38, 5: 1073–1077.

43. Kazuaki Tanaka, Naomi Yamashita, Hideyuki Nakanishi, and Hiroshi Ishiguro. 2016. Teleoperated or autonomous?: How to produce a robot operator's pseudo presence in HRI. In *Human-Robot Interaction*, 133–140.

44. Wei Chung Teng, Yi Ching Kuo, and Rayi Yanu Tara. 2013. A teleoperation system utilizing saliency-based visual attention. *IEEE International Conference on Systems, Man, and Cybernetics*: 139–144.

45. Jacqueline M Kory Westlund, Marayna Martinez, Maryam Archie, Madhurima Das, and Cynthia Breazeal. 2016. A Study to Measure the Effect of Framing a Robot as a Social Agent or as a Machine on Children' s Social Behavior. *Human-Robot Interaction*: 459–460.

46. Kevin W Williams. 2004. A Summary of Unmanned Aircraft Accident / Incident Data: Human Factors Implications. *FAA Civil Aerospace Medical Institute*, December 2004: 18.

47. Holly A. Yanco and Jill Drury. 2004. "Where am I?" Acquiring situation awareness using a remote robot platform. In *IEEE Systems, Man and Cybernetics*, 2835–2840.

48. J. J. Young, H. Z. Tan, and R. Gray. 2003. Validity of haptic cues and its effect on priming visual spatial attention. *Haptic Interfaces for Virtual Environment and Teleoperator Systems*: 166–170.

49. James E. Young, Richard Hawkins, Ehud Sharlin, and Takeo Igarashi. 2009. Toward acceptable domestic robots: Applying insights from social psychology. *International Journal of Social Robotics* 1, 1: 95–108.

50. James E. Young, Youichi Kamiyama, Juliane Reichenbach, Takeo Igarashi, and Ehud Sharlin. 2011. How to walk a robot: A dog-leash human-robot interface. In *2011 RO-MAN*, 376–382.