Influences of the Robot's Colour and Shape within Human-Robot Interaction

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(after Bicchi et al., 2008)
Abstract

Human-robot interaction is an important field of research to enable human friendly industrial environments and new methods for more efficient production, both today and in the future. One aspect is the influence on human beings from colour and shape seen from a psychological perspective. A literature study has been done to gain results about the human impression of and reaction to colours and shapes. Further a research has been done to evaluate student opinions about the use of some specific colours on industrial robots and shapes of robot grippers.

In the research it has been established that white and orange are preferred over red and blue as colours on industrial robots, from a perspective of caused anxiety. This corresponds with earlier results in the literature; white is a colour that is seen as calm, orange is used in dangerous environments to utilise its catch of attention. The other section of research was focused on shapes of robot grippers and the optimisation to gain a reduction of their caused anxiety. Significant difference in caused anxiety could just be found between two grippers; a robot hand and a two-finger gripper with sharp and angular construction, with preference for the robot hand.
Sammanfattning


Det kunde konstateras att vitt och orange som färg på industrirobotar föredras framför användning av röda eller blå, sett ur ett perspektiv av orsakad ångslan. Resultatet stämmer överens med tidigare studier återgivna inom den litteratur som studerats; vitt ses som en lugnande färg och orange är använd i riskfyllda miljöer för att öka uppmärksamheten. Studiens andra del behandlade robotgripdon och syftade till att minska deras orsakade ångslan. Signifikant skillnad i orsakad ångslan fanns endast mellan två gripdon; en robothand och ett gripdon med två fingrar med vass och kantig konstruktion.
I would like to thank Dino Bortot for supervision, advices and help during the work with this bachelor thesis, as well as for the subject of research in this project. I also would like to thank Ulf Sellgren for suggestions during the way.

Caroline Lindberg

Stockholm, August 2011
The nomenclature lists symbols, abbreviations and acronyms, with following description, used within this bachelor thesis.

**Notations**

<table>
<thead>
<tr>
<th>Symbol</th>
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<tr>
<td>$B$</td>
<td>Number of bins</td>
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<tr>
<td>$d$</td>
<td>Degrees of freedom</td>
</tr>
<tr>
<td>$E_k$</td>
<td>Expected number</td>
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<tr>
<td>$G$</td>
<td>Normal distribution</td>
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<tr>
<td>$N_{x,y}$</td>
<td>Extension of sample</td>
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<tr>
<td>$N$</td>
<td>Number of respondents</td>
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<tr>
<td>$O_k$</td>
<td>Observed number</td>
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<tr>
<td>$R$</td>
<td>Number of anxiety statements</td>
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<tr>
<td>$T$</td>
<td>Anxiety sum</td>
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<td>$v$</td>
<td>Number of events</td>
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<tr>
<td>$\sigma$</td>
<td>Standard deviation</td>
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<td>$\chi^2$</td>
<td>Chi-squared</td>
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<td>$\hat{\chi}^2$</td>
<td>Reduced Chi-squared</td>
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**Abbreviations and acronyms**

<table>
<thead>
<tr>
<th>Abbreviation</th>
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<tr>
<td>ASIMO</td>
<td>Advanced Step in Innovative MObility</td>
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<td>CAD</td>
<td>Computer-Aided Design</td>
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<td>DOF</td>
<td>Degrees Of Freedom</td>
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<td>HRI</td>
<td>Human-Robot Interaction</td>
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<tr>
<td>RAPHaEL</td>
<td>Robotic Air Powered Hand with Elastic Ligaments</td>
</tr>
<tr>
<td>ROSETTA</td>
<td>RObot control for Skilled ExecuTion of Tasks in natural interactions with humans; based on Autonomy, cumulative knowledge and learning</td>
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<tr>
<td>SCARA</td>
<td>Selective Compliant Assembly Robot Arm</td>
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<tr>
<td>STAI</td>
<td>State-Trait Anxiety Inventory</td>
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<tr>
<td>TCP</td>
<td>Tool Center Point</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENT

1 INTRODUCTION .................................................................................................................. 1

1.1 BACKGROUND ................................................................................................................ 1

1.2 PURPOSE ........................................................................................................................ 1

1.3 DELIMITATIONS .............................................................................................................. 2

1.4 METHOD ........................................................................................................................ 2

2 FRAME OF REFERENCE ....................................................................................................... 3

2.1 ROBOTS .......................................................................................................................... 3

2.2 DESIGN OF INDUSTRIAL ROBOTS ............................................................................ 4

\hspace{2.2.1} Industrial Robots of Today ................................................................. 4

\hspace{2.2.2} Industrial Robots of Tomorrow ................................................................. 7

2.3 HUMAN-ROBOT INTERACTION ................................................................................ 8

2.4 HUMAN SENSE OF SECURITY .................................................................................. 11

2.5 HUMAN PERCEPTION OF COLOUR .......................................................................... 12

2.6 HUMAN PERCEPTION OF SHAPE .............................................................................. 14

3 HYPOTHESES AND QUESTIONS ..................................................................................... 17

4 RESEARCH METHOD ....................................................................................................... 19

4.1 METHOD FOR THE SURVEY .................................................................................... 19

4.1.1 Questionnaire .......................................................................................................... 19

4.2 ANALYSIS METHOD .................................................................................................... 23

\hspace{4.2.1} Analysis of the preference questions ...................................................................... 24

\hspace{4.2.2} Analysis of the open questions ........................................................................... 24

5 RESULTS ........................................................................................................................... 25

5.1 RESULTS FROM THE GENERAL COLOUR RESEARCH ............................................ 25

5.2 RESULTS FROM THE COLOUR-ON-ROBOT-RESEARCH ......................................... 27

5.3 COMPARISONS OF THE TWO COLOUR RESEARCHES ........................................... 29

\hspace{5.3.1} Open questions regarding robot colours ............................................................. 29

5.4 RESULTS FROM THE SHAPE OF GRIPPER RESEARCH ........................................... 30

\hspace{5.4.1} Open questions regarding robot grippers ........................................................... 33

6 DISCUSSION AND CONCLUSION .................................................................................... 34

6.1 DISCUSSION .................................................................................................................. 34

\hspace{6.1.1} Colour Preferences ................................................................................................. 34

\hspace{6.1.2} Preferences for Robot Grippers .......................................................................... 35

6.2 CONCLUSION ................................................................................................................. 35

7 RECOMMENDATIONS AND FUTURE WORK ................................................................ 36

7.1 RECOMMENDATIONS ................................................................................................. 36

7.2 FUTURE WORK ............................................................................................................... 36

8 REFERENCES ...................................................................................................................... 37

APPENDIX A: QUESTIONNAIRE .......................................................................................... 42
1 INTRODUCTION

In this chapter the background, purpose and delimitations for this bachelor project are presented. The chapter also describes methods used during the project.

1.1 Background

Since the 1950s robots have been developed. They were introduced in the industry at the 60ths (Robot, 2011) and the future will most likely show a development of a society with human-robot coexistence (Weng, et al., 2009). In the industry, robot assistance is used for an improved productivity at traditionally manual workplaces. Example of tasks in manufacturing environments are fetching, carrying, assembling, handling and measuring. Beside robots can also be possible improvers for the workers’ health care (Salvini, et al., 2010). Already 2004 the Fukuoka World Robot Declaration (International Robot Fair, 2004) summarised some expectations for the next generation of robots. In the declaration it was stated that future robots will be partners that co-exist with human beings, assist the human beings physically and psychologically and contribute to the realisation of a safe and peaceful society.

The coexistence of human and robot, and the dynamic interaction between them in general, is called Human-Robot Interaction, HRI. The study of HRI includes a wide complexity; from the design of robot systems to the way humans socially interact with robots, as well as how to accomplish a safe and effective interaction. The HRI’s impact on both human users and the society is now under increasingly consideration, for example, robots which are meant to work together with humans cannot strictly follow the conventional safety rules applied for industrial robots.

The embodiment is one of the most obvious attributes of a robot; its physical design and its influence on social interactions are important parts of the HRI. The design, including factors like colour and form, has an influence on the human being’s psyche, so also within the HRI. In addition the development of the coexistence, the human wellbeing should be taken in consideration. All interactions between human and robot shall work harmonious irrespective of robot shape, size and appearance.

1.2 Purpose

The purpose of this bachelor project was to acquire knowledge on psychological factors within human-robot interaction. Research about HRI-safety has till now mainly focused on decreasing the risk for physical harm from the robot. Factors that were considered were those that were supposed to have influence on the human well-being, psyche and behaviour such as fear and irritation level. Focus was on the influence on the individual from colour of the robot and shape of the robot’s tool, in this case a gripper, placed at the end-effector, also called tool center point, TCP. This subject has until now only reached an inconsiderable investigation within the HRI-field. With the development of HRI, the robot will probably turn from a machine which colour, and to some extent shape, is chosen to be seen and to warn against hazards and protect the human from injuries and accidents into an appearance that is psychologically better for the human user.

The head question that was considered was: How are human-beings psychologically influenced from the choice of colour on robots and shape of industrial robot grippers?

It could be differentiated in the following questions and thesis:

Which colours and shapes give the best well-being? Does the human feel safer within an industrial environment when surrounded by specific colours and shapes?
1.3 Delimitations

The main field of focus in this thesis was the psychological influence of robot colour and shape at the TCP. Delimitations were done according to the survey; a smaller group of students in the field of mechanical engineering participated. Besides, also the size of the questionnaire was limited, with focus on some specific colours and shapes. Limitation in time was another ground to restrictions and pictures of robots and robot grippers was used for the survey to examine differences in experiences due to different colours and shapes.

1.4 Method

The project was accomplished mainly through a literature study, especially on the psychological field, regarding the influence on the human being from different shapes and colours on subjects, especially technical components in movement.

Further, a survey was done, principally to get knowledge about the experience of some specific shapes and colours within the human-robot interaction. The method was a questionnaire, in which the valuation method, the use of scales as well as a standard and accepted procedure was considered. To gain more knowledge about the influence of specific colours and shapes in the manufacturing, some open questions were included in the end of the questionnaire.

For the survey and the interviews a CAD model, Computer-Aided Design model, of an industrial robot was used together with pictures of robots and other objects that were be changed in respect to colour. Further pictures of some robot grippers were used in the survey.
This chapter presents the theoretical reference frame that was required for the following survey. Background information about robot standards, human-robot interaction and psychological influences from colour and shape are described.

2.1 Robots

A robot is a mechanical intelligent machine, electronic or digitally programmed, that independently can perform tasks, to different degree autonomous executed, i.e. on its own or with guidance from a human. There are different aims for robots depending on their tasks, autonomous ones, that are meant to perform tasks and interact in a human surrounding, and others that are developed for specialised work, used in dangerous environments or in tasks not suited for the human body. Robots are today used for a wide field of applications; either for example for nursing and households, as service robots, or in industry. Both fields are examples of utilisations were robots play an increasing role. Robots are also well-suited for insertion in environments that are classified as dangerous. As an example thereof the Fraunhofer Institute for Manufacturing Engineering and Automation, Fraunhofer IPA, (2009a) can be mentioned, they have developed robot applications for offshore inspections and security supervision among other things.

The word robot originates from the name of robot-resembling humans in a play written 1921 by Karel Čapek (Zunt, 2004). The word robota in Czech means work or toil. Back then robots with today’s technology were not able to be built, but they have since then taken part in art and entertainment and with new technologies the development of robots has seen increasing investigations. The first real autonomous robot were developed 1948 by Grey Walter and had the shape of a turtle (Bridgman, 2004). Since then great advances have been done and the last years the robot “family” has seen members like both robot lawn mowers, see Figure 1a., assisting robotic instruments for surgery, special robots for exploration of Mars and humanoids (Malone, 2010). Humanoids are built to imitate humans and their mobility, perception and cognitive skills etc. Their application in the future is intended to be as assistants in everyday duties as for example personal robots. That goal has caused a progress for autonomy system; path planning, speech, and systems for communication through a human-friendly design. One example of a humanoid is ASIMO, Advanced Step in Innovative MObility, see Figure 1b.

![Figure 1. Examples of different types of robots; a. A robot lawnmower called Automower 305 (Husqvarna AB, 2011). b. ASIMO, a humanoid (Honda, 2009).](image-url)
future goals for robots. But robots are not expected to, within the next decades, be able to show human features like adequate human talk, creativity, empathy and understanding (Capurro, et al., 2008). A substitution of humans to robots would overall lead to both standardisations and mechanisations and reduce social behaviours where they are applied.

2.2 Design of Industrial Robots

Within the industry, machines with a flexible behaviour have been inserted in factories as a competitive instrument. They have been developed to improve economic and qualitatively productive factors through automation. The development is under a continuous intensive and extensive progress. The primary commissions for these machines have been and still are to execute tasks in manufacturing industries that fasten up production, reduce costs and decrease the risk for physical harm on employees. Machines and especially robots are useful tools especially in environments that are dangerous for humans and where human limits are wised to be crossed, for instance where high precision is needed, when heavy weights are to be carried, for a speed-up of processes, in scales not suited for humans and for work which demand an endurance that a human cannot match (Heinzmann, et al., 2003). Robots are also well suited for repeated activities and at locations that can be dangerous or poisonous. The first industrial robot, made in the 1950s by Unimation Inc., was a hydraulic arm, called Unimate, used for heavy lifting in a repeated sequence of motions, see Fel! Hittar inte referenskälla. It was developed for and sold mainly to the automobile industry and first introduced 1961 by General Motors (Robot, 2011). During the 1960s and 70s more advanced electric arms with cameras were developed at the Massachusetts Institute of Technology and at Stanford University. In the 80s Japanese and European manufacturers entered the field and made the automation more advanced (Robot, 2011). The driving forces for nowadays developments are in addition to arguments above also threats for an aging population and its consequence on the society. The trend for the upcoming future shows a deeper integration of human-robot interaction also in the industrial field.

2.2.1 Industrial Robots of Today

Today robots are configured and inserted in industrial surroundings for a wide range of tasks, an example is the use of robots for cab assembling in the car industry, see Figure 2. The worldwide number of operational industrial robots were 2009 slightly more than one million (IFR, 2010), with an estimated supply of approximately 110 000 units (Lindqvist, 2011). The International Organization for Standardization (ISO 8373) has defined a robot as an automatically operated machine, designed with a manipulator, possible to be used in multipurpose ways, programmable in three or more axes and also reprogrammable. It performs complicated repetitive tasks with high accuracy and is traditionally placed in relatively static environments, but in accordance with ISO 8373, it can either be stationary or free to move. A robot shall also have the capability to perceive its surroundings. In industrial applications manufacturing robots traditionally work in isolated settings, because of the risks for human injuries, since they usually work with high speed and do carry heavy weights. To achieve their goal, they are more or less acting autonomous. Reasons to invest in robots have, except from safety issues in high risk industries, been cost and quality. System changes in the production are expansive and interrupt the production, but when they are integrated in the robot system, the production line can be easier switched between models and the automation can enable better just-in-time production (Heyer, 2010).
A robot consists of the manipulator and a control device with communication interface including hard- and software (ISO 10218). The part of the manipulator with which the robot accomplishes its work is called the Tool Center Point, TCP, or end-effector and is defined as the mechanism at the end of the joint structure (ISO 8373). The total system is called robot system and includes the robot or manipulator, end-effector(s) and further devices, i.e., tools that the robot need to accomplish its work and fulfill its duties, for example sensors and other equipment and last but not least an operating system (ISO 10218). The tool at the TCP is often high complex and matched for one specific task, it can be suited to handle products or to pick them up, either many at once, or in a special optimized order. Examples of robot tools are grippers, welding devices and tools for grinding and deburring. The robot gripper is a type of tool used to hold or move parts from one location to another. Their design varies with task; hard jaws are suited for high precision but are deficient when flexibility is needed. Then soft jaws can be used while they can better comply with part variations. Further on, it can be a dual gripper, as in Figure 3, or a gripper with higher adaptability like in Figure 4, that can use four modes to grasp: cylindrical, spheroid, pinch with two or three fingers. A gripper can be driven either with hydraulic, electrically or pneumatically, or eventually use vacuum or electromagnets (RobotWorx, 2011).

Figure 2. Robots used at Scania for welding in the cab assembly line (Scania, 2006).

Figure 3. A dual robot gripper with articulated joints (Robot for Students, 2011).

Figure 4. An adaptive robot gripper with three fingers (Robotiq, 2010).
General safety rules are based on the management of risks and analysis of risks as function of consequences and probability of an event (Piggin, 2005). Some functions for the interface used to keep the safety are displaying of robot status, drive status, operating mode, local and remote emergency stop, and status of guarding equipment (Piggin, 2005). Today’s robots used in manufacturing industries are often placed in closed safety zones based on the prevention of collisions. For an actual impact, a reduction of the joint stiffness would only slightly reduce the impact dynamics between a robot and the human head for somewhat flexible robots (Haddadin, et al., 2009), so the safety zones are justified. Due to safety regulations, people are, mostly, during the robot’s work time strictly forbidden to enter the workspace, which includes the entire zone reachable by the robot. Safety areas can be controlled with light grids, laser scanners and special safety controllers and are used to minimise the interference between humans, robots and other surrounding objects. Usually this type of safety zones lead to minimisation of collaboration and the only interaction will be concentrated to when the robot is turned off. Eventually, a human can be allowed to enter the robot’s work space while the robot is working at low speed, adjusted to reduce the risk of physical harm. This reduced speed is stated in ISO 10218, as a limited velocity by which the human shall be able to step aside, or stop the robot, before danger occur and it is not permitted to exceed 250 mm/s. The reduction concerns both the TCP and the robot flange. Another criterion for determining industrial robot’s safety is the robot’s predictability and the possibility to know the machine behaviour in advance (Salvini, et al., 2010).

The kinematics of an industrial robot usually consists of four to six coupled driven joints (Hägele, 2009). The way they are connected and manoeuvred limits the robot’s degree of freedom, DOF. A robot is free to move in a number of DOFs limited by its design and the total DOFs for a robot are six (ISO 8373). In the kinematic definition of manipulating robots, the joint structure as well as the robot workspace is included. A Cartesian robot consists of parallel struts, arranged side by side, rendering possible motions in a block-shaped workspace, see Figure 5. A SCARA, Selective Compliant Assembly Robot Arm, has three rotational DOFs and one translational, see example in Figure 6, and is convenient for planar handling and assembling, which also can be fast performed (Hägele, 2009). Further on also cylindrical, spherical, articulated and parallel kinematics are examples of existing possible robot structures, all with different axis of rotation and positions of the DOFs.

Figure 5. Sketch of the kinematics in a cartesian robot, with three translational degrees of freedom (Wikipedia, 2007)
2.2.2 Industrial Robots of Tomorrow

An ambition for future industrial robots is to design and produce them to be able to work in a more lean, economic and flexible way; they shall be suited for a broad spectra of tasks, fast installed and work as a replacement of humans in dangerous surroundings, works and situations, with a wished possibility to enable an insertion of robots in both large and smaller companies. A superior goal is to develop robots that can take over operations in a line that traditionally are manually accomplished (Björn, 2011). Such workplaces can further be complimented with inclusion of human-robot interaction; the barriers between robots and their human co-workers could then be removed and they could share their workspace as well as cooperate to achieve the same goal for their task, then the automation can be increased and lead to cost reduction. Another expectation is an incorporation of robots and automation systems also in companies with smaller production batch for example through higher flexibility, efficiency and high capacity in its applications, one such robot is the rob@work 2-system, developed by Fraunhofer IPA (2009b), see example in Figure 7. It is built to be easy reconfigured or changed and to choose its workplace flexible.

To render a development of future social robots, new technologies have to be implemented, for example methods for sensing and robot intelligence. That requires sensory technologies for perception both of patterns, sound and vision as well as body language and face recognition. After analysing its sensorial impressions, the robot shall be able to interact in a socially accepted way and respond both to humans and other robots (Ge, 2007). When it comes to industrial robots, though, they will probably also in the upcoming future be constructed and designed after standards with more limited tasks of performance, compared to for example service robots purposed to be used in elderly care or personal robots with application in households. Today, no established safety criteria exist and also no norms for collaborating robots. One consortium
working on this theme is ROSETTA, RObot control for Skilled ExecuTion of Tasks in natural interactions with humans; based on Autonomy, cumulative knowledge and learning (Björn, 2011).

The opening of safety cells is one of the expectations with HRI. That would create collaboration cells, areas in the production cell with special protection devices in which the robot and the human during operation can execute tasks simultaneous (ISO 10218). Robot safety is able to be increased through mechanical design, for example by elimination of sharp and dangerous edges, use of elastic material as cover and padding on the robot arm, reduction of the moment of inertia for the robot arm and TCP and a reduction of the robot’s weight with for example lightweight materials (De Santis, et al., 2007). These safety measures have to be made under the consideration that the robot still shall be able to perform real tasks without losing its abilities, otherwise it would lose some of its technical advantages (Giuliani, et al., 2010, Heinzmann, et al., 2003). Additional methods can be combinations of electronic software safety procedures with external respective internal robot sensing. Sensors can for example be used to measure distances to human users and other objects, like nearby situated robots. Robots have to be implemented with necessary collision detecting systems (Heinzmann, et al., 2003) and the robot’s motion path can then be planned to be collision avoiding while executing its tasks (De Santis, et al., 2007). During the work cycle different safety zones can be used and some forbidden zones, where the robot is not allowed to enter, can be defined. As a compliment virtual walls can control where humans and robots are allowed to cooperate. In a case of immediate hazard emergency stops are not to prefer since they totally shuts down the robot and it is likely that an inspector has to start it up again. With safety controllers and by the use of their standstill mode, the robot’s speed can be scaled to zero and emergency stops could be avoided (Stopp, et al., 2004). Safety controllers can be used also to prevent turnovers, pinches and collisions, for example due to the ability to shut down components, stop the robot’s motion and apply the brakes (Piggin, 2005). As another application they can be introduced to observe whether the TCP and joints are moved in an allowed speed, that the TCP does not leave defined areas and that joint angles are kept permitted (Stopp, et al., 2004).

Expectations for the future is that robot technologies will see more safety, more flexibility, increased accuracy, ease of use, more speed, less use of space, and less energy consumption (Lindqvist, 2011). Further also the try to insert robots in areas with low degree of automation is mentioned.

2.3 Human-Robot Interaction

The study of the interaction between coexisting robots and humans is called the human-robot interaction, HRI. It is an interdisciplinary field based on subjects like psychology, computer science and art (Dumas, et al., 2009). Among many topics it includes knowledge of communication and interfaces between human and robot, how to design appropriate and convenient robots and considerations of safety issues for them through a user-friendly design. Important is the consideration of the human’s safety and possible risks during the development of closer respectively more intensive interaction with robots.

The first reflections about HRI were introduced in the 1940s by Isaac Asimov, who wrote three laws of robotics, as follows: A robot may not injure a human being, or through inaction, allow a human being to come to harm. A robot must obey the orders given it by human beings except where such orders would conflict with the first law. A robot must protect its own existence as long as such protection does not conflict with the first or second law (Asimov, 1942 cited in Robot, 2011). These laws are in some extent to be considered also nowadays in the development of the HRI.
One of the basic goals with HRI is to combine the robot’s qualities with the human cognitive and sensory ability and capability to reason and react impulsive. Such realisation would enable a division of a total work operation in smaller part operations, after how they are best suited to be performed, through a flexible automation of the working processes, in a trustful and accountable way, see Figure 8. To approach this concretisation, future robots have to act firstly in a secure way and secondly strive for an efficiency kept at the wished level. This requires a great amount of new technologies which shall make the robot capable to detect humans, plan its motions and tasks, interact, respond and behave intelligent (Ge, 2007) also if the robot’s immediate surrounding is unstructured and includes other dynamic elements like humans or other robots. Directives for actions and safety are also stated by Fraunhofer IPA (2005); work segments shall be suitable designed for industry with considerations to arrangement and processes, tasks shall be done after relevant standards to minimise risks and standard components shall be used. With an introduction of these safety technologies and application of new safety standards an opening of the robot’s work cell can be possible.

Figure 8. Example of a possible situation with cooperating human and robot (after Bicchi, et al., 2008).

An example of HRI in an industrial environment is given by the Fraunhofer IPA, (2005) which have developed a robot called PowerMate, see Figure 9. It’s used for assembling of rear axle gears. The robot fetches a gear and moves it to where it’s going to be attached. Then the human takes over the control of the robots motions and makes the precise positioning. After fastening the bolts, the robot fetches a new gear while the operator makes other tasks. Except steering by hand, as in this example, the interaction can also include human insertion or supervision of speed, distance and used power (Björn, 2011).

Figure 9. Human-robot interaction by Fraunhofer IPA with PowerMate, an industrial robot (Fraunhofer IPA, 2008).

Furthermore, different cultural rules in the human to human interaction are to be taken in consideration during development of future robots and can furthermore be used as hints for communication principles (Trafton, et al., 2005). The human-human communication includes steps like recognising, engaging, transmission of information, physical motions and intimacy as well as methods to recover after mistakes (Goodrich, et al., 2007). Robots will preferably have to act in a, for many varying cultures, socially accepted way and communicate with an intuitive manner through speech, facial expressions and body language. One method is to use knowledge
about the human-human interaction and apply it on HRI by mirroring the interaction. Human-like motions and behaviour will make the human feel more comfortable (Nonaka, et al., 2004). Nevertheless, the interaction among humans is not to, and cannot, be fully transferred and implemented on robots since humans for instance have other translational and rotational moving pattern, can easily read body language and interpret touching as parts of the communication.

The human-robot communication is important in both directions; the human speech, gestures, facial expressions and writing has to be perceived by sensors and also interpreted and understood by the robot, irrespective of the user’s individual disparity (Dumas, et al., 2009). In the HRI-case gestures have to be detected, one method is skin colour detection which is complicated by wear of gloves, variable illumination, cluttered backgrounds etc. (Wöhler, 2009). Further on, to fulfil the interaction loop, defined as dynamic systems of action and perception by human and robot in a dynamic environment, see Figure 10, the robot also has to give output modalities like text, visual and audio expressions which the human can percept through sight, hearing and touch (Dumas, et al., 2009). These interfaces demands more technologies than those used in the human-computer interaction where the interface traditionally are based on keyboard, mouse and screen (Wöhler, 2009).

![Figure 10: The interaction-loop with human, robot and environment, after Iossifidis et al. (2004).](image)

One possible risk for injury is the risk for a collision between robot and human, when they are intended to cooperate. If the power transferred by the robot is too high, the user can come to harm. The HRI comprises different fields where methods to perceive humans, motion planning and cognitive models are some of them. The perception includes both vision of the environment and speech recognition. In anthropic environments the robot trajectories has to be well planned. The motion has to be perceived by the user as logic and easily recognised, and when it does, the robot can be said to fulfil a human-friendly concept, like in a research made by Heinzmann, et al. (2003). Motions that appear to be unexpected, fast or not visible enough could cause fear for the user. To prefer are motions equal to those that could be performed by humans (De Santis, et al., 2007). Not only the working speed is to take in consideration, robots have to have a fast reaction time to keep an eventual present human safe, i.e. the robot has to understand the situation, react to unknown situations and detect dangerous occasions as soon as they may occur (Giuliani, et al., 2010). This point of view is called the awareness of the HRI, here applied on the robot-human direction. Generally, the awareness of HRI is used to assure that the considerations of HRI are followed in a sufficient way with well-functioning coordination between user and robot. The awareness of HRI can be divided in differently defined subfields, human-robot, robot-human and robot-robot, as mentioned above. Human-robot awareness is based on the human’s understanding of location, activities, status and surroundings of the robot. The robot-human case bases on the robot’s knowledge about the human’s commands, which probably will see an improvement with time and more research, and the involvedness of robots in society and industry (Echterhoff, et al., 2006). Further, the robot-robot awareness means the knowledge robots have of commands from other robots and the coordination between them. This point of view can also be expanded to include the humans’ overall mission awareness, by which the
human’s understanding of the goals with the human-robot activities and the progress compared to the goals are meant (Drury, et al., 2003).

Future robots will need to use autonomous systems to be able to work and interact in an unstructured anthropometric society (De Santis, et al., 2007). The interpretation of robots as social and cooperating partners is a question that interests the social psychological research (Echterhoff, et al., 2006) and a human-like communication with robots is desired. Preferably is also a development in direction to more human-friendliness; technics to manually instruct the robot, to teach by showing i.e.

The Fraunhofer Institute for Manufacturing Engineering and Automation, Fraunhofer IPA, (2011) has summarised some expectations and trends in the progress of the HRI; the safety observance will be developed with hardware like built-in cameras and safety controllers, like those under adaption by ROSETTA, in standardised safety systems. Further, new norms for the interaction and collaboration will be established and the work division between human and robot will be implemented as a governing economical factor (Fraunhofer IPA, 2011). But the expected increase of application of HRI has to be considered also in the future. In World Robotics 2007 (2007, cited in Björn, 2011) it was pointed out that the HRI is best suited for production that traditionally have been done manually, i.e. for high-cost and small volume products. This field is called the HRI-Zone, see Figure 11.

![Diagram](image)

Figure 11. The HRI zone graphically depending on produced volume and cost per part (after World Robotics, 2007, cited in Björn, 2011).

### 2.4 Human Sense of Security

The human psyche is influenced by the human’s environment; surrounding objects are visually detected and stimuli are capturing attention. Within this topic the psychological approach of the feel of safety is in focus, particularly on the impact of visual impressions from colours and shapes. The sense of security is based on the probability of different risks and possible effects of these risks. Mental safety means that humans do not feel fear of or get surprised from objects they are exposed for, like co-operating adjacent robots, further shall the robot not cause unpleasant or disgusting feelings for its user (Nonaka, et al., 2004). Sensorial inputs from the surroundings influence emotional biases and for those emotions the amygdala, a section of the limbic system in the brain, plays an important role. It has influence on and takes part in the processing of emotional events like threatening and fear related stimuli (Vuilleumier, 2005, Sander, et al., 2003). Threats are origins to emotions like anger, fear and anxiety. The detection of threatening stimuli depends on earlier experiences, but the speed of detection varies in studies. A threatening stimuli, like an attacking animal, were by adults not shown to be detected faster
than pleasant stimuli (Tipples, et al., 2002), but 3-years old children could, according to former negative experiences, detect syringes faster than pens (LoBue, 2010), also Flykt’s (2005) results confirmed faster reaction times for threatening elements, especially in grey scale pictures. Related to these results a study from Yantis (1993) confirms that the capture of attention by stimuli depends of the human task, when one single object are searched for, all given stimuli would capture attention, but when no deliberate object is searched for, only new stimuli will catch attention.

Human perception and physical reactions as effect of visual impressions can be physiologically measured, with methods like heart rate, heart variance, blood pressure, skin conductivity and the galvanic skin response to get an indication of a human’s arousal and evaluate the person’s emotional state (Bartneck, et al., 2009). One example is colour depending reactions, which can be a variability of blood circulation and muscular power, influenced by at least blue, green, yellow, orange and red colours (Arnheim, 1997).

A, for humans, visual salient element is conceived to be different from surrounding objects in at least one dimension. These dimensions of impression can be colour, form, luminance etc. (Turatto, et al., 2000). Proofing examples are a red ball on a green lawn, a camouflaged bird in a tree or one square-shaped plate among round plates on a table. In the next two sections the physical theory of vision and psychological aspects to perception of colour and shape are considered.

2.5 Human Perception of Colour

The human eye can distinguish almost 2.3 million different colour hues (Pointer, et al., 1997) under presence of three necessary components for perception; light source, object and observer (Arnheim, 1997). The colour of an object comes from either generated or reflected wavelengths of light and stimulates sensor cells in the eye, see Figure 12, that register the visible wavelengths of electromagnetic radiation (Colour, 2011). The colour vision process starts in the three kinds of retinal cone photoreceptors. They are mainly concentrated in the fovea, but also spread over the whole retina, which cover a great part of the inside of the eye and contains about 130 million of photoreceptors (Pfizer, 2011). The retinal cone photoreceptors are sensitive to light and able to register light of wavelengths in the visible spectra, 380-780 nm. Each type of the cone photoreceptors can register different wavelengths, partly corresponding to the three colours red, green and blue (Gegenfurtner, et al., 2003). The light absorption goes through conversion from electromagnetic energy into electrical voltages and further into action potentials. The information is sent via the optic nerve to the brain’s visual cortex and there combined to enable perception of different colour hues (Gegenfurtner, et al., 2003).

![Figure 12. The anatomy of a human eye (Healthy Eyes, 2011).](image-url)
The appearance of colour can besides change with viewing conditions, as medium, light source, background and luminance level, this variability is called colour inconstancy (Arnheim, 1997). All colours are defined by three attributes; brightness, saturation and hue (Color theory, 2011), see Figure 13 a. and b., but the terminology varies in the literature. The hue corresponds to the wavelength of light and is the characteristic that separates colours like red, green and blue (Crozier, 1996). The brightness is considering light- and darkness, which corresponds to the amplitude of the light waves. The saturation, also called chroma, describes the colour intensity; light with fewer different wavelengths appear to be more saturated (Crozier, 1996).

Figure 13. a. A three-dimensional representation of the colour-influencing factors hue, saturation and brightness (here lightness). b. A two-dimensional diagram with hue and brightness (Jameson, et al., 2001).

Colour tends to contribute to different degrees of positive or negative feelings. It is one of the strongest stimuli humans receive from their exterior (Mahnke, 1996) and tend to contribute to arousal in the brain (Robinson, 2004). Feelings or preferences for different colours, i.e. their hue, saturation and brightness are to some part innate (Mahnke, 1996) however not totally human consistent, but depend to different degree on gender, age, personality, cultural and geographical effects, cognition etc. Colours that are vivid, bright and saturated tend to be more preferred and associated to positive feelings than dark or greyish colours (Tangkijviwat, et al., 2008, Ou, et al., 2004) and by children the preference inclines to increase with age (Boyatzis, et al., 1994). In general, the gender-specific preference is somewhat similar (Ou, et al., 2004, Boyatzis, et al., 1994) and in some studies not even taken in consideration (Jansson-Boyd, 2011). In identical pictures, one version with colour and the other in grey scale, humans tends to focus on different locations, because of the influence of colour on the human attention (Frey, et al., 2008). Also Mahnke (1996) confirmed that eyes are most attracted by bright colours and big contrasts. Colours can be seen as coupled to different feelings or characteristics. In a description by Mahnke (1996) the colour orange were seen as exciting and stimulating when bright, and when light as cheering. It’s associated as lively, energetic and extrovert and also intrusive when saturated. White on the other hand is the colour describing light, hope, cleanness, goodness, innocence etc. Grey stands for conservative, quite, calm and passive.

In the field of vision, the eyes are most attracted by areas with bright colours or big contrasts (Mahnke, 1996). Preference for some colours compared to other is being discussed in terms of nature versus nurture. From an evolutionary point of view, colour preference has a steering function that makes humans and animals attracted to some colours and keeping away from “bad looking” (Palmer, et al., 2010). They are also presenting arguments for the learning of preferences, that colours can be liked because of what they are associated with, and give examples, e.g. that adults might like blue while it’s the colour of a clear sky. The way colours are aesthetically seen and what humans consider them to express depends also on cultural colour associations. Aslam (2006) describes meanings of colours in different countries with a wide distribution of associations. The meaning of one single colour in the comparison diversifies between as distinguishing attributes as happiness versus disease or evil versus dependable.
Crozier (1996) compared results from 10 studies of colour preferences and found that the most preferred colour hue was blue and yellow was the least preferred. This corresponds with results from many other studies. In a study made by Jansson-Boyd (2011) shapes with red circles were found to be observed like more complex than blue circles. The test also showed that blue shapes were deemed to be more familiar and more attractive, where the attractive apprehension correlated with description of interest, but negative correlated with complexity and mystery. They also compared light- and dark-shaded elements and ascertained that light-shaded elements were observed as more familiar. Blue was also found to be more preferred compared to other colours in a study by Palmer et al. (2010). The red colour hue is commonly associated with power, Crozier (1996) mentions its association with blood and fire as a possible reason. Red is also arousing and exciting with associations diversified between passion, intensity and aggressiveness (Mahnke, 1996). Not only the colour hue corresponds to arousals, colour saturation is summarised by Crozier (1996) to have a greater influence of influencing arousal than different hues have.

Within machinery some rules for basic safety colours is to be considered (Mahnke, 1996). Colours can for instance be used to improve the perception of dangerous or critical parts of machines. Use of focal colours, in other words bright or contrasting, would attract the eyes to these areas. In this field especially red, yellow and orange are of importance. Red is according to architectural advices the colour for containers with dangerous contents and buttons or switches on machines (Mahnke, 1996). Yellow is used to attract people’s attention and to warn against physical hazards. Orange designates danger and is used for exposed edges and on machine parts that may cause an injury through crush, cut, shock etc.

Theories about colour psychology are also criticised. Popular culture information about colours, like those that yellow creates anger and frustration, red causes excitement, green relieve stress and that blue gives feelings like calmness are by O’Connor (2011) described as based on anecdotal evidence and not always on empirical evidences, additionally, she calls such information rather factoids than facts.

2.6 Human Perception of Shape

The mental feeling of safety is to great degree influenced by visual impressions and protects the human from possible hazards. The human sense does not only include impressions of safety, as warnings for danger, based on colours, but also aspects like the form of an object. The robot design includes wide spread fields from electrical and software design to mechanical design, but in this section the focus lies on the shape of the robot manipulator and specifically on the tool at the TCP. Due to the strive to develop a considerate HRI in industrial fields this is a subject to take in consideration. The embodiment of the robot, including shape, size and motion are influencing factors (Nonaka, et al., 2004).

The contour of an object influences the human’s impression of safety. Sharper objects are by the human seen as more dangerous than curved objects. In studies made by Bar and Neta (2007, 2006) it was shown that humans disliked sharp-angled objects and patterns more than curved, when comparing grey scale pictures of different emotionally neutral everyday objects as well as novel patterns, see examples in Figure 14. They compared their results with feelings of threat caused by the sharp angles and found a, somewhat low, human comparison between sharp objects and threat (Bar, et al., 2007). No gender-specific differences were found. Their study also gave results showing that sharp angled objects result in a stronger activation of the amygdala, a part of the limbic system of the brain, see Figure 15, compared with curved objects. Also in comparison with pointing features curved contours can be preferred and within car interior design, curved designs are preferred and valued as more attractive (Leder, et al., 2005). Jansson-Boyd (2011) has in a study of aesthetic concepts found that the shapes of squares are perceived
to be more complex and interesting than circular shapes. The study also showed high ratings for complexity and interest with mixed shapes, containing a mixture of squares, circles and unfamiliar shapes. Increasing number of objects had influence on all of the concepts, mystery, complexity, interest as well as of familiarity and Jansson-Boyd (2011) drove a conclusion that the amount of shapes contributes with how the stimuli is perceived.

![Examples of curved and sharp-angled objects and patterns](image1)

**Figure 14.** Examples of curved and sharp-angled objects (above) and patterns (below) that was compared in a study by Bar and Neta (2006).

An example of a sharp object, which can be seen as threatening and correlates with negative subjective emotional ratings, is the V-shape (Larson, et al., 2007). It can be compared with shapes in an angry face as eyebrows, chin and mouth. Experiments made by Larson et al. (2007) showed that stimulus of different shapes could capture and maintenance attention to varying degree. The V-shape was detected more rapid than non-threatening objects like an upward pointing V or a circle.

![The position of the amygdala in a human brain](image2)

**Figure 15.** The position of the amygdala in a human brain (Wikipedia, 2006).

Except the study of contours also size plays a matter in the preferred embodiment of elements. Hiroi and Ito (2008) found that the difference between a robot’s height and the height of the observer’s eyes had an influence of the subjective acceptable distance. When the object is taller than the subject’s eyes, the acceptable distance is as largest. They make the conclusion that robots taller than 1800 mm are not suited for working close to humans, because of the anxiety they cause.

In the consideration of a human-friendly embodiment of robots the influence of motions does also take part in the human wellbeing. Some examples will here be presented. Robots must at appearance of humans reduce their motion speed and their movements as well as make their noise lower (Hanajima, et al., 2005). Robot motion with coordinated movement of arm and body is preferred over uncoordinated motions and gives good impressions on humans (Nonaka, et al., 2004). Hanajima et al. (2005) found, that in an experience with a slowly moving robot the distance were more crucial for the skin conductance response than the speed and during robot motion adjacent to humans, the electro dermal activity responses tended to increase. In
comparison to distant movements approaching motions by robots gives stronger stimuli for humans (Hanajima, et al., 2005). Findings by Woods et al. (2006) showed that humans at least preferred robot motion when approaching in front of them compared with approaches from left and right; this was found with test both live and video based showed on a screen.
3 HYPOTHESES AND QUESTIONS

This chapter concentrates on questions and hypothesis which could not be answered in the previous theoretical section. To conclude, two hypotheses are presented, which were expected to be verified through the following method chapter in this thesis. Further, two hypotheses were stated as a concentration of the questions of interest.

The reference frame has given background information about the human-robot interaction and the influence of shapes and colours on the human psyche. These theories are to be bound together and more specifically studied for the case of human interaction with industrial robots.

Theories and research in the colour psychology field already stated that when humans are asked to value colours after preference vivid colours are more liked than dark (Tangkijviwat, et al., 2008, Ou, et al., 2004) and bluish more than red or yellow colours (Jansson-Boyd, 2011, Palmer, et al., 2010, Crozier, 1996). But is this the case also in dangerous environments and situations like in the co-working with an industrial robot? Do humans prefer to get arousal feelings like described by Robinson (2004) and take advantage of the attention different colours can give, pointed out by Frey et al. (2008) or do they prefer to be surrounded by colour that traditionally are seen to cause calm and relaxed feelings, like white or maybe blue (Mahnke, 1996)?

Four colours were chosen to be used for the research; orange while it is the traditional colour used on industrial robots, blue and white while they in accordance with the reference frame are seen as calm and non-threatening. Further also red was chosen to give a comparison to orange and while it is a colour that have been under research before and is shown to be seen as dangerous.

Hypotheses to take under investigations are:

- Red and orange as robot colours distract the human from its task within HRI.
- Red and orange as robot colours cause stress for the human co-worker within HRI.
- White and blue as robot colours make the human focus better on its tasks during HRI.
- White and blue as robot colours influence the human calming within HRI.

Based on these hypotheses following questions regarding the choice of paint on robots can be written:

- How do you feel for this colour?
- Would you feel distracted by this colour?
- Do you feel stressed by this colour?
- Would you realise that a robot painted in this colour could be dangerous?
- Do you feel safe for a robot painted in this colour?
- To feel safe, which colour would you prefer as paint on this robot?

The field of research expands further when also shapes are taken in consideration, but the scientists seem to agree on one conclusion. Sharp angled elements and objects are seen as threatening and complex (Bar, et al., 2007, Larson, et al., 2007) and curved objects are preferred and found as more attractive (Jansson-Boyd, 2011, Bar, et al., 2007, Leder, et al., 2005).

Hypotheses:

- A tool at the TCP with curved shaped is preferred by a worker in the HRI.
- A tool at the TCP with sharp angles is less preferred by a worker in the HRI.
- Higher number of fingers on the gripper decreases the anxiety.
- A tool at the TCP with blunted shape causes less anxiety than one with a sharp shape.

Questions based on these hypotheses:

- Do you feel safe with the shape of this gripper?
How dangerous do you experience this robot gripper to be?
How distracted do you feel from the shape of this robot gripper?
How safe do you feel for this robot gripper?
Which robot gripper do you prefer the most?

These questions can be concentrated, due to interest and delimitations, in the following two hypotheses which are the statements to be investigated in the continuation of this bachelor project.

- In the HRI, a robot painted in red or orange cause more anxiousness than one painted in white or blue
- A round shaped, blunt robot gripper placed at the TCP cause, within the HRI, less anxiousness than a sharp shaped robot gripper.

The direction of the dependency is in both hypotheses well defined and obvious; the human is to different degrees supposed to be influenced by attributes of a vicinity robot.
4 RESEARCH METHOD

This chapter describes the research method. The process behind the construction and analysis of quantitative surveys are taken in consideration and described, as well as its application on the used questionnaire. Finally a description of the data analysis is presented.

The method was chosen as an approach to the field that built the foundation of the research. It was done to render a possibility to describe the psychological influence on the worker in the HRI from robot colour and shape of robot grippers. Essential was also to make the collection and analysis of the data transferable into other industrial settings than just the one studied.

The here described part of the research was done with a survey, built partly based on the state-trait-anxiety inventory method, STAI, and complemented with a few open questions. The open questions were chosen to give information about the respondents expected psychological experience from work with a robot of a specific colour and their thoughts about robots operating in other scenarios. The purpose of the open questions was also to get a more complete understanding of how colour and shape actually can have an influence and in how deep degree a possible co-worker are conscious thereof.

4.1 Method for the Survey

The goal with a quantitative survey is a verification of hypotheses and to determine the strength of the investigated effect (Mayer, 2009), so also in this research. The hypotheses for which this bachelor project took its concerns were, as given in the last section; if a red or orange painted robot is more disliked and causes more anxiety, in the HRI, than one painted in white or blue and if a round shaped, blunted robot gripper placed at the TCP is more preferred, in the HRI, than a sharp gripper. Beside of that, also an analysis of the influence of number of robot fingers was done. The chosen method was a questionnaire, presented below.

A survey is a method to collect information from people, about them, their opinions and their knowledge. The answers will help to explain, describe, compare or predict one or more subjects of interest with the aim to produce reliable and valid data. It shall be accomplished in an arranged or designed environment to gain useful and valid result. The survey shall preferably be based on six features (Fink, 2003); specific measurable objectives, sound research design, sound choice of population or sample, reliable and valid instruments, appropriate analysis and accurate reporting of results. Measurable means that the survey’s purpose is clear described. Research design has with the environment of the study to do, i.e. participants, places and activities during the study. The sampling is, as described above, a question of how the participants are chosen. The instrument can be, and was in this case, a questionnaire. It is reliable when it gives a consistent result and valid when the obtained result is accurate. The analyse method is depending on the sample and the purpose of the study. The results shall finally be reported fairly and accurately, including tables and graphics. Except these guide lines Mayer (2009) also notes that questions for which all participants are expected to give the same answer to shall be avoided.

4.1.1 Questionnaire

The chosen instrument for this study was a questionnaire, written completely in English, the whole questionnaire can be seen in Appendix A. To enable an appropriate quantitative analysis, it was a partly standardised questionnaire, basically built with closed questions written under consideration of some guidelines from Scholl (2009). Every respondent got the same questions with identical formulations. The order was kept constant, but could alternatively have been randomised. Answer alternatives was already given. The respondent had for every question to find the answer that best corresponded to his/her spontaneous open answer. All questions and instructions were formulated in a neutrally and clear way.
The questionnaire was constructed and based on the hypothesis and questions of research but suited to the participants and written to enable a quantitative analyse of the respondents’ subjective estimated feelings. The psychological experiences of robot colours and tool shapes are qualitative characteristics, also called latent variables. Nevertheless, through discretisation of every attribute in variables, the individual psychological experience could be valued as quantitative data. To fulfil the logic in the questionnaire some clear psychological stimuli were used and paired together in opposites, as defined in Table 1. In the table anxiety-free statements can be seen to the left and statements that describe anxiety are presented to the right.

Table 1. Psychological stimuli that were used in the research, anxiety-free to the left and anxiety describing to the right.

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Calm</th>
<th>Stressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comfortable</td>
<td>Nervous</td>
<td></td>
</tr>
<tr>
<td>Safe</td>
<td>Dangerous</td>
<td></td>
</tr>
<tr>
<td>Losing concentration</td>
<td>Getting distracted</td>
<td></td>
</tr>
</tbody>
</table>

All stimuli were used in different statements. The formulation of each statement was kept constant in every section of the questionnaire, but the order was randomised for every shape and colour under consideration. The statements were also rewritten for every section to suite the question of topic. Examples of statements were *This colour reminds me of comfort*, *When the robots are painted like that, I think I would feel nervous* and *When the robots are painted like that, I think I would feel calm*. The answer scale consisted of four disjunctive alternatives, i.e. either-or answers. The four categories were based on the State-Trait Anxiety Inventory, STAI, questionnaire as *Not at all*, *Somewhat*, *Moderately so* and *Very much so*.

The STAI is a method developed in the 1970s by Charles Spielberger. It consists of two questionnaires which comprise the state-anxiety and trait-anxiety fields, with 20 questions each. The goal with the model is to achieve knowing about adults’ anxiety both as a state and as a trait. It is suited not only for evaluation of stressed situations, but also to situations of neutral or positive character (Laux, et al., 1982). Spielberger (1972, cited in Laux, et al., 1982) defined the anxiety state as an emotional condition, characterised by tension, nervousness, inner concern respective fear for future incidents and also as an enhanced activity in the autonomous nervous system. He also meant that the anxiety, seen as a state, varies with time and situation. The trait-anxiety part of the STAI is mentioned to be used for a normalisation of the anxiety sum for every single respondent. The goal is thereby to equalise the anxiety for individuals, which can be more or less nervous or anxious.

Due to its adaption and good application for cases when anxiety in specific situations is under investigation and since the hypotheses in this thesis are based on a thought that red and orange colours on robots will cause greater anxiety than white and blue as colour since they are thought to be seen as neutral, respective that round and blunted shapes on robot tools are estimated as less anxiety causing than sharp shapes, the anxiety-state part of the STAI was used as a ground for the questionnaire used in this research. As in the STAI questionnaire some statements were mixed. Four were formulated as feelings of anxiety and four as opposite, anxiety free statements, in Table 1 defined as calm and stressful stimuli. Every statement could be responded to with one of four answer alternatives as mentioned above.

The results were first analysed for every participant. Like in the STAI model all answers were given values from one to four. All anxiety free statements, with words that described calm stimulus, were inversed through a differentiation from the value five. The sum of the given answers for every question represents the intensity of an emotional condition (Laux, et al., 1982). The addition gives an item score, which is an index for how anxious every respondent is to every colour or shape of consideration (Scholl, 2009). For the eight used statements in this
questionnaire the sum will be able to vary from 8 to 32, were 32 corresponds to the most stressed stimuli or highest grade of anxiousness.

The survey was divided into four sections; general colour cases, connection to Human-Robot Interaction, robot tools and finally comments, with open formulated questions. The three first sections had in common that they started with a small introduction to a given case. For every case the participants were encouraged to respond for their impression with the below standing statements while looking at the given objects.

The first section consisted of pictures of five objects, a belt, a wrench, a pillow, a door and a cup, see Figure 16. The objects were changed with Adobe Photoshop Elements in colour to represent the four colour nuances of consideration; bright orange, bright red, bright blue and white. The pictures were chosen to show objects that could be expected to be seen as anxiety free. They were except from colour exact copies of each other, chosen like that to minimise influences from other factors than just colour differences. The respondents were requested to imagine themselves in an environment dominated by the given colour nuance. They should envision themselves in this environment for a long period of time and respond with below standing statements. For every colour six statements were written, the psychological stimuli safe and dangerous were excluded because of the anxiety-neutrality of the chosen objects.

Every answer option was graded from 1 to 4 divided by intensity, were 1 stood for the alternative Not at all.

![Figure 16. Example of objects that were used in the first part of the questionnaire, in the colours blue, red, orange and white, a. (after Wrench Handles, 2011), b. (IKEA, 2011), c. (after Polardörren, 2011), d. (after Arabia, 2011).](image)

The colour research was continued by a concentration on the HRI in respect of the psychological impression of colours in combination with robots. Four industrial robots in different positions were coloured in the same nuances as above, three of them were real robots and one was a CAD-model, see Figure 17. Statements were given below, now with all eight stimuli from Table 1. The participants got a case where they worked in a factory, in close cooperation with an industrial robot for several hours. They were encouraged to give their answers with respect of the colour nuance of the robots.

As a second part the respondent was requested to place the robots in order of preference for every statement. The ranking was done so that the most preferred gripper was given a one, the second most preferred a two and so on.
The third part was focused on tool shapes; the chosen kind of robot tools was grippers. The respondents were introduced to the grippers with a short explanation that they are tools placed at a robot’s end effector. Also in this section a case was given; the participant was working in a factory, where work close to a robot for several hours was necessary. For every gripper the robot could use it was asked for respond on the statements. Five grippers were used. They were showed in equal big pictures and rotated to the same angle (60° to the right). They all differed from each other in design of shape, see Figure 18. Also other attributes, as material and colour, differed between the grippers, but the respondent was requested to not pay any regard thereon. The first robot gripper was a dual gripper with articulated fingers and straight parts connected in some angles. Gripper nr 2 had the shape of a hand, called RAPHaEL, Robotic Air Powered Hand with Elastic Ligaments and is produced by students at Virginia Tech (Virginia Tech, 2009). It had five fingers and also the articulation of a hand. The third gripper was dual and had two stiff and rounded fingers. The fourth was a three finger gripper with sharp and stiff fingers. The fifth and last researched gripper was an adaptive gripper produced by Robotiq (2010) with three articulated 3-jointed fingers.

![Grippers](image1.png)

Figure 18. Robot grippers of different shapes that were used in the questionnaire, 1. (Robosavvy, 2011), 2. (Virginia Tech, 2009), 3. (after Budget Robotics, 2011), 4. (after Beep Control, 2011), 5. (Robotiq, 2010).

Characteristic attributes for the five grippers regarding number of fingers and shape were defined, and can be seen in Table 2.

<table>
<thead>
<tr>
<th>Gripper Attribute</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fingers</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Construction</td>
<td>Angular</td>
<td>Curved</td>
<td>Curved</td>
<td>Angular</td>
<td>Curved</td>
</tr>
<tr>
<td>Angels shape</td>
<td>Sharp</td>
<td>Blunted</td>
<td>Sharp</td>
<td>Sharp</td>
<td>Blunted</td>
</tr>
</tbody>
</table>

Table 2. Attributes for the five grippers that were used in the research.
4.2 Analysis Method

The colour depending anxiety was analysed for all four colours, both for the general case and for the case including robots. The data was pre-processed with an inversion of the answers generated from anxiety-free statements; the inversion was done through the calculation of the difference between the value 5 and the rate of the, in the questionnaire marked, grade of agreement. Further, the anxiety sum for every participant was calculated.

For every colour and object of investigation the mean value of the anxiety sums, $\bar{T}$, and their standard deviations, $\sigma$, for the $N$ respondents were calculated. This was done to enable a comparison between the anxiety caused by the different colours or objects under consideration.

$$\bar{T} = \frac{\sum_{i=1}^{N} T_i}{N} \quad (1)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (T_i - \bar{T})^2}{N-1}} \quad (2)$$

The normalised values, $T_{in}$, for all anxiety sums, depending on number of anxiety statements, $R$, were calculated, as well as the normalised mean values, $\bar{T}_n$. The normalisation was done to give values between 0 and 1, to make a comparison of sums calculated from the different parts of the questionnaire possible. Further the propagated error, $\sigma_n$, was calculated.

$$T_{in} = \frac{T_{i-R}}{4-R-R} = \frac{T_{i-R}}{3R} \quad (3)$$

$$\bar{T}_n = \frac{\sum_{i=1}^{N} T_{in}}{N} \quad (4)$$

$$\sigma_n = \sqrt{\left(\frac{1}{4R-6}\right)^2 \cdot \sigma^2} \quad (5)$$

The distribution of $T_i$ was plotted together with the normal distribution multiplied with the number of participants, $N$. The normal distribution, $G_{\bar{T},\sigma}(T)$, describes the distribution and depends on the mean and standard deviation of the examined events. It represents a symmetric distribution and is valid when the random errors are small and systematic errors are negligible (Taylor, 1997). Here it means that $G_{\bar{T},\sigma}(T)$ describes the probability to get an exact value for the anxiety sum for the mean value $\bar{T}$ and the standard deviation $\sigma$. Multiplied with $N$ the distribution gives the number of counts for every anxiety sum value.

$$G_{\bar{T},\sigma}(T) = \frac{1}{\sigma \sqrt{2\pi}} e^{-((T-\bar{T})^2)/2\sigma^2} \quad (6)$$

As the next step of the analysis the Chi-squared, $\chi^2$, test was done. The $\chi^2$ describes the quality of the fitting of for example a curve to measurements. For many measurements and a good fitting the $\chi^2$ should be equal to the degrees of freedom, $d$ (Taylor, 1997). In the formula below $O_k$ is the observed number, the number of participants for every value of anxiety sum between $R$ and $4 \cdot R$. $E_k$ is the, with the normal distribution, expected number of measurements for the test. The bins were called $k$ with the total number $B = 4 \cdot R - R + 1 = 3 \cdot R + 1$ that was as many as the possible distribution for the anxiety sum.

$$\chi^2 = \sum_{k=1}^{B} \frac{(O_k - E_k)^2}{E_k} \quad (7)$$
Further, the reduced Chi-square, $\tilde{\chi}^2$, was calculated through a division with the number of degrees of freedom, $d$, which here was $d = B - 3$ because of the three constrains used to calculate $E_K$. The value of the reduced Chi-squared, $\tilde{\chi}^2$, can be used to give an indication of the significance of the distribution. With the use of Taylor (1997 p. 293) the probability of a value of $\tilde{\chi}^2$ greater than the observed $\tilde{\chi}_0^2$ was read from table. To read data from the table, interpolation was needed, and therefore equation (8) was used.

$$ y = \frac{(y_2-y_1)}{(x_2-x_1)}(x - x_1) + y_1 $$ (8)

To prove if the means of the anxiety sum of the colours differed from each other a double t-test was done, according to guidelines from Mayer (2009). The double t-test performs a test to prove the null hypothesis that data from two independent and random samples from normal distributions have equal means and variance. The null hypothesis stands against the possibility that the means are not equal. Assumptions that, according to Mayer (2009), have to be done are that the samples have a quantitative scale level, are generated from a normal distributed population or consist of more than 30 samples. Further the different variances have to be taken in consideration. The test is done through a comparison of the test statistics whether $|t|$ is smaller than the critical value $t_{\alpha;n-2}$, where $t$ is calculated with equation (9), with $n_x$ and $n_y$ as the extensions of the samples. $t_{\alpha;n-2}$ can be found tabulated. From tables the value of $\alpha$ can be found, were $\alpha$ is the significance level, if $\alpha$ is 0.05 it means that the significance level is 5 % and likewise for other significance levels.

$$ t = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{\sigma_x^2}{n_x} + \frac{\sigma_y^2}{n_y}}} $$ (9)

The double t-test was done for all comparisons between colours and grippers and results and significance levels are presented in the next chapter.

### 4.2.1 Analysis of the preference questions

Histograms were done to visualise the preference of the colours and robot grippers. Each colour or object was given a number from one to five as a ranking of the preference. The plots showed qualitatively what the respondents preferred over other colours and grippers. Every colour could with these results give an indication of the grade of preference for the specific colour when compared with the other.

### 4.2.2 Analysis of the open questions

The last part of the questionnaire consisted of four open questions. The purpose was to get some more insight in colour and shape preferences and to let the respondents give their own opinions about the colours without the boundaries of the boxes to mark in the closed questions. According to Mayer (2009) the answers was categorised in different alternatives to enable analyse of the results. The open questions were used as a complement to the quantitative results and as a way to describe calculated differences in anxiety for different colours and shapes.

Two of the questions were regarding colours on robots. They were formulated to encourage the respondents to describe their feelings for colours on robots used in HRI situations and factors that improved the comfort in such a situation. The other two was asked to get an insight of which factors on the design of robot grippers that the participant saw as most important for human wellbeing.

The analysis of this section was done through a quantification of the answers. The answers were grouped together and summarised to explain results from earlier sections in this research.
This chapter presents the results gained from the method described in the process development chapter together with analysis and comparison to the theory given in the frame of reference.

All data were collected with a questionnaire, see Appendix A, and analysed with Matlab. The research group consisted of 33 mechanical engineering students, 9 at KTH Royal Institute of Technology in Stockholm and 24 at Technical University Munich. 25 of the respondent were male and eight were female, all of them had an age between 18 and 29 years. The respondents were not well experienced with human robot interaction, 52% answered that they had no and 39% that they had minimal experience from HRI and one participant estimated the experience from HRI as high. To environments with industrial robots; 39% had no, 48% minimal and 15% moderate experience, again one respondent valued the experience as high.

The participants were also asked about when they last saw an industrial robot in person, even if their experience was low, the answers here indicated more. 12 persons saw a robot within the last month, including the last half a year totally 20 respondents, that is 61%, answered that they had seen an industrial robot. When the situation of the “robot meeting” was asked for, four persons answered in a direct cooperation with a robot. Eight of the respondents had worked in an industrial environment including robots, including two of the four with experience of direct cooperation.

The respondents got the questionnaire either printed on paper or sent to them by e-mail and they were encouraged to respond to the questionnaire in a quite environment and to ponder over their answers. After collecting the questionnaires all results were transferred into a computer and calculated results are presented below.

5.1 Results from the general colour research

First the results from the general colour section were analysed, 33 respondents answered to this section and the survey consisted of six statements. The mean of anxiety sum, $T$, was calculated as well as the standard deviation, $\sigma$, for the four colours of consideration, the results are presented below, in Table 3. The value of the anxiety sum could in this section vary between six and 24, which gives $B=19$.

<table>
<thead>
<tr>
<th>Colour</th>
<th>Blue</th>
<th>Red</th>
<th>Orange</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of anxiety sum, $T$</td>
<td>12.2</td>
<td>16.0</td>
<td>14.6</td>
<td>13.3</td>
</tr>
<tr>
<td>Standard deviation, $\sigma$</td>
<td>2.6</td>
<td>2.5</td>
<td>2.8</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 3 shows that most anxiety was caused by the red colour followed by orange, white and blue. This can also be seen in Figure 19.
Figure 19. Mean anxiety and standard deviation for the four colours, from the right, blue, red, orange and white.

Histogram for the anxiety sum for all four colours in the general colour case was done to illustrate the distribution of the data and to get an apprehension of the grade of anxiety. The results are presented in Figure 20. In the figure also the normal distribution, calculated with equation (6), can be seen, as the black curve.

![Graphs showing distribution of anxiety](image)

Figure 20. Distribution of the anxiety sum for all participants in the case with different objects plotted together with the normal distribution, as the black curve.

Already a view on the graphs gives that the differences between the different colours are small. As a second step the $\chi^2$ was calculated for all four colours to enable a comparison of the distribution with the normal distribution. Also the reduced Chi-squared, $\tilde{\chi}^2$ was calculated through a division with the degrees of freedom. Here the number of bins was 19, which gave $d = 17$. Results are presented in Table 4. The probability to get the same result for $\tilde{\chi}^2$ in a new research was read from appendix D in Taylor (1997) and interpolated for more exact results. Results are also presented in the table. It can be seen that the probability to get a normal distribution is high for all four colours.

<table>
<thead>
<tr>
<th>Colour</th>
<th>Blue</th>
<th>Red</th>
<th>Orange</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^2$</td>
<td>7.76</td>
<td>10.85</td>
<td>10.56</td>
<td>20.07</td>
</tr>
<tr>
<td>$\tilde{\chi}^2$</td>
<td>0.46</td>
<td>0.64</td>
<td>0.62</td>
<td>1.18</td>
</tr>
<tr>
<td>$Prob_d(\tilde{\chi}^2 \geq \tilde{\chi}^2_{0.05})$ [%]</td>
<td>96.3</td>
<td>86</td>
<td>88</td>
<td>27</td>
</tr>
</tbody>
</table>

The result for the probability shows that the significance level of 5 % is widely exceeded. That means that it is possible to get the same result in a new study under the same conditions.
To evaluate if the distributions of the anxiety sum for the four colours differ significantly from each other a double t-test was done, see equation (9).

Table 5. The double t-test for the different colours in the general case.

<table>
<thead>
<tr>
<th>Compared colours</th>
<th>Blue-Red</th>
<th>Blue-Orange</th>
<th>Blue-White</th>
<th>Red-Orange</th>
<th>Red-White</th>
<th>Orange-White</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double t-test α</td>
<td>0.001</td>
<td>0.001</td>
<td>0.2</td>
<td>0.05</td>
<td>0.001</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The results from the double t-test in Table 5 show that the distributions differ from each other to a significance level smaller than 0.1 % for the colour pair blue-red, blue-orange and red-white. For the colours red and orange the distributions differed to a significance level of 5 %. By the other combinations no significant difference in distribution could be found.

### 5.2 Results from the colour-on-robot-research

The procedure above was done also for the data from the section in the questionnaire that focused on colours on robots. Also here 33 persons answered to the questionnaire, but eight statements were given. The anxiety sum could vary between eight and 32. Calculated mean and standard deviations are presented in Table 6.

Table 6. Mean and standard deviation for the anxiety sum produced from the questionnaire with colour on robot.

<table>
<thead>
<tr>
<th>Robot colour</th>
<th>Blue</th>
<th>Red</th>
<th>Orange</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of anxiety sum, $\bar{T}$</td>
<td>20.4</td>
<td>21.9</td>
<td>17.9</td>
<td>15.9</td>
</tr>
<tr>
<td>Standard deviation, $\sigma$</td>
<td>1.9</td>
<td>4.1</td>
<td>4.1</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Also here a graphic from the values was done, see Figure 21.

![Figure 21. Mean anxiety and standard deviation for the four colours applied on industrial robots, from the right, blue, red, orange and white.](image)

Histogram with the distribution was done with a comparing normal distribution, see Figure 22.

![Figure 22. Distribution of anxiety sum and the calculated normal distribution, as the black curves.](image)
The reduced Chi-squared was calculated for the four colours and further also the probability to get the same or a higher $\bar{\chi}^2$ in a new research. The degrees of freedom, $d$, was 23, while the number of bins was 25 and two constraint existed, the number of participants and the mean of the anxiety sum. It can be seen in Table 7 that the significance level of 5 % is passed for all colours except blue. That means that the anxiety sums are highly consistent with normal distributions for the colours red, orange and white. The distribution of the anxiety sum for blue disagrees with a normal distribution to a significance level of 5 %.

Table 7. The $\chi^2$ for the four colours applied on robots.

<table>
<thead>
<tr>
<th>Colour</th>
<th>Blue</th>
<th>Red</th>
<th>Orange</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^2$</td>
<td>12.36</td>
<td>18.09</td>
<td>23.69</td>
<td>18.70</td>
</tr>
<tr>
<td>$\bar{\chi}^2$</td>
<td>0.54</td>
<td>0.79</td>
<td>1.03</td>
<td>0.81</td>
</tr>
<tr>
<td>$\text{Prob}_d(\chi^2 \geq \bar{\chi}^2_d)$ [%]</td>
<td>95.3</td>
<td>74.5</td>
<td>42.6</td>
<td>72.1</td>
</tr>
</tbody>
</table>

As in the last section the double t-test was used to analyse the significance level for the differences between the four colours. It can be seen in Table 8 that all the distributions for the colour pairs blue-white, red-white and red-orange differ from each other to a significance level of 0.1 %, the disagreement is highly significant. The colours blue and orange differed to a significance level of 1 % and orange-white to 5 % significance level. Directly contrary to the results from the general colour case no significance could be found for the difference between the anxiety for blue and red.

Table 8. The double t-test between the different colours on industrial robots.

<table>
<thead>
<tr>
<th>Compared colours</th>
<th>Blue-Red</th>
<th>Blue-Orange</th>
<th>Blue-White</th>
<th>Red-Orange</th>
<th>Red-White</th>
<th>Orange-White</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double t-test: $\alpha$</td>
<td>0.1</td>
<td>0.01</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The part of the questionnaire where psychological influence from colour in combination with HRI was analysed was divided in two sections. The second gave information about which colour the participant preferred over the other for every statement. The respondent ranked the colours after preference for which he/she preferred the most. In Figure 23 it can be seen that in the overall preference, orange was most chosen as robot colour, white as the second. In the same figure it can also be seen that red was the least preferred, with the largest number of fours.

![Figure 23. Histogram over the preference of the colours on robots.](image)

Also here a double t-test was done to prove the significance of the differences, see Table 9. Orange differed from both blue and orange to a significance level of 1 %, which was the case also for red-white. Blue differed from white to a significance of 5 % and the colours blue-red and orange-white did not differ significant.
Table 9. Double t-test for colour preference.

<table>
<thead>
<tr>
<th>Compared colours</th>
<th>Blue-Red</th>
<th>Blue-Orange</th>
<th>Blue-White</th>
<th>Red-Orange</th>
<th>Red-White</th>
<th>Orange-White</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double t-test: α</td>
<td>0.4</td>
<td>0.01</td>
<td>0.05</td>
<td>0.01</td>
<td>0.01</td>
<td>0.4</td>
</tr>
</tbody>
</table>

5.3 Comparisons of the two colour researches

As a comparison of the anxiety caused from colour of the objects showed in Figure 16 and anxiety cause from colours on robots in Figure 17, in a figured HRI-situation, all anxiety sums and standard deviations were normalised with formulas (3) to (5) and Figure 24 was produced. In the figure it can be seen that for the colours blue and red the combination with the robot increased the total anxiety, but for orange and white it was not the case.

Figure 24. Mean anxiety and standard deviation for the four colours applied on objects and on industrial robots, from the right, blue, red, orange and white.

5.3.1 Open questions regarding robot colours

Two of the open questions, asked in the end of the questionnaire, considered colours on robots. Their aim was to get a description of feelings for colours on robots used in HRI situations and factors that improved the comfort in such a situation. 27 persons answered to the colour related questions, not every respondent gave opinion to every colour. Only a minority of the participants, eleven persons, uttered themselves about blue, one meant that the nuance was too dark, ten saw it as a well suited robot colour and described comfort with the words calm, comfort, good, safe and not aggressive. The colour red was only described as good by one person and additional as attention catching by one. Eleven respondents meant that the colour made them either stressed, distracted or nervous, alternatively as a colour that felt dangerous or aggressive.

Orange was the colour that most of the participants wrote about, 21 persons gave reasons for or against the colour. Preference for the colour was argued for in terms of attention and good frightening by 15 respondents. Three persons saw the colour as warm or coupled to happy feelings. The fact that orange is a standard colour on industrial robot and therefor chosen as favourite was mentioned by 6 persons, by which two of them also belong to the participants that meant that orange catches attention. 18 persons choose to discuss white as robot paint and 16 thereof expressed positive meanings, words that were used to express those feelings were all describing comfort; like calm, safe, not dangerous, further was the colour deemed to be good. The colour was also described as neutral. Three respondents were of another opinion; that white was too hard to see and because of that not suited as robot paint.
Overall positive words were more used than negative, except for red, the majority of the words used described advantages with the colours, like desirable feelings as comfort or attention. The meanings from the open questions mostly agreed well with the results analysed above, see Figure 24. Red was seen as most frightening and agreed to the greatest mean anxiety sum. White and orange were mentioned in mostly positive words, and were also the colours with lowest anxiety mean, see Table 6. The answers regarding blue did not agree very well with analysed results. In the research with blue as robot colour the distribution of the anxiety sum did not differ significant from the data for the red colour. But in this part of the questionnaire, blue was mentioned in positive terms by ten of eleven, which is almost 91 %, which is almost the opposite of the description of red, which was described as negative by eleven of 13, approx. 85 %.

5.4 Results from the shape of gripper research

For each of the five grippers in Figure 18 the mean and standard deviation for the anxiety sum was calculated, results are presented in Table 10. Eight statements were used and 33 persons answered to this part of the questionnaire, the value of the anxiety sum could also here vary between eight and 32.

Table 10. Mean and standard deviation for the anxiety sum produced from the part of the questionnaire with robot grippers.

<table>
<thead>
<tr>
<th>Gripper nr</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of anxiety sum, $\bar{T}$</td>
<td>20.1</td>
<td>18.2</td>
<td>19.0</td>
<td>19.4</td>
<td>19.2</td>
</tr>
<tr>
<td>Standard deviation, $\sigma$</td>
<td>3.7</td>
<td>3.8</td>
<td>4.3</td>
<td>3.9</td>
<td>3.9</td>
</tr>
</tbody>
</table>

In Table 10 it can be seen that the mean values of the anxiety sum for the different grippers did not vary to a great extent, it is also made clearer in Figure 25, where the mean anxiety sum for the five grippers are plotted together with their standard deviations. Both the table and the figure show that gripper one and four gave the greatest mean anxiety sums. This can be compared with the attributes from Table 2. The two grippers have in common that they both were constructed in angular shapes. Besides they were also characterised by sharp angels in their shape.

The distribution of the respondents’ individual anxiety sum can be seen in Figure 26. In the figure the normal distribution is also showed, as the red curves.
Figure 26. Distribution of the participants individual anxiety sum and the calculated normal distribution for the five robot grippers.

The probabilities for the Chi squared were calculated for the five grippers, with \( d = 23 \), results are presented in Table 11. As the table shows, all distributions agreed very well with the normal distributions.

Table 11. The \( \chi^2 \) for the five robot grippers compared with normal distributions.

<table>
<thead>
<tr>
<th>Gripper nr</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \chi^2 )</td>
<td>17.34</td>
<td>20.04</td>
<td>19.78</td>
<td>14.31</td>
<td>15.32</td>
</tr>
<tr>
<td>( \hat{\chi}^2 )</td>
<td>0.75</td>
<td>0.87</td>
<td>0.86</td>
<td>0.62</td>
<td>0.67</td>
</tr>
<tr>
<td>( Prob_d(\chi^2 \geq \hat{\chi}^2) )</td>
<td>78.5</td>
<td>63.9</td>
<td>65.3</td>
<td>91.5</td>
<td>86.7</td>
</tr>
</tbody>
</table>

For the five grippers no clear differences in distribution occured for the anxiety sum, so as in the last section the double t-test was used to analyse the significance level for the differences in anxiety sums for the five grippers, see Table 12. Significant difference only occurred between the gripper number one and two, to a level of 5 \%. As a comparison of the distributions also Figure 27 was done, the normal distributions for all grippers were plotted together to illustrate the relative small differences in anxiety sum. The figure confirms the result mentioned above, greatest difference occured between gripper nr 1 and 2.

Table 12. The double t-test between the different anxiety sums for the robot grippers.

<table>
<thead>
<tr>
<th>Compared grippers</th>
<th>1-2</th>
<th>1-3</th>
<th>1-4</th>
<th>1-5</th>
<th>2-3</th>
<th>2-4</th>
<th>2-5</th>
<th>3-4</th>
<th>3-5</th>
<th>4-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double t-test ( \alpha )</td>
<td>0.05</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.8</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
</tr>
</tbody>
</table>

Figure 27. The normal distributions for the five grippers. The differences was greatest between gripper 1 and 2.

One hypothesis under consideration was the dependence of the number of gripper fingers, \( F \), on the anxiety sum, \( T \). To evaluate the dependence a least square fit to a straight line (equation (10))
was done. That gave the constants $k = -0.43$ and $m = 20.45$. The fitting was plotted together with data collected from the questionnaires and can be seen in Figure 28.

$$T = k \cdot F + m$$ \hspace{1cm} (10)

Figure 28. The dependence of the anxiety sum from the number of fingers on the robot gripper. In blue the mean anxiety sum with standard deviation collected from questionnaires is shown and the red curve shows a least square fit to the data.

To evaluate the quality of the fitting the reduced Chi-square was calculated as well as the probability to get a $\bar{\chi}^2$ that is the same or larger than the one from this research, results are shown in Table 13. The degree of freedom was 2 since the used data was from five grippers and constraints were the number of grippers as well as mean of the anxiety and their standard deviations. The probability was almost 100 %, which means that the fitting is consistent with the collected data. But this results have also to be considered with the knowing that only gripper 1 and 2 caused anxiety sums that differed from each other on a significant level.

Table 13. The $\chi^2$ for the difference between the least square fitting and data from questionnaire regarding anxiety sum dependence on number of robot gripper fingers.

<table>
<thead>
<tr>
<th>Gripper nr</th>
<th>$\chi^2$</th>
<th>$\bar{\chi}^2$</th>
<th>$Prob_d(\bar{\chi}^2 \geq \chi^2_d) \ [%]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.030</td>
<td>0.015</td>
<td>98.7</td>
</tr>
</tbody>
</table>

The research was continued with some questions were the respondents were asked to place the grippers in order of preference. The results for the preference are made visible in Figure 29. It can be seen that gripper nr 2, the robot hand, was the most preferred gripper with the highest amount of ones. Except from that no clear differences could be found in preference.
Figure 29. Histogram over the grade of preference for the robot grippers.

The double t-test was done to give knowing about if significant differences occurred between the preferences. Significant differences to at least a significance level of 5% occurred between gripper 2 and each of the grippers 1, 3 and 4. That means that gripper 2 was significant preferred over the grippers 1, 3 and 4.

Table 14. Double t-test for differences in preference of the robot grippers.

<table>
<thead>
<tr>
<th>Compared grippers</th>
<th>1-2</th>
<th>1-3</th>
<th>1-4</th>
<th>1-5</th>
<th>2-3</th>
<th>2-4</th>
<th>2-5</th>
<th>3-4</th>
<th>3-5</th>
<th>4-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double t-test α</td>
<td>0.01</td>
<td>0.8</td>
<td>0.4</td>
<td>0.1</td>
<td>0.01</td>
<td>0.05</td>
<td>0.2</td>
<td>0.6</td>
<td>0.2</td>
<td>0.4</td>
</tr>
</tbody>
</table>

5.4.1 Open questions regarding robot grippers

The two last open questions considered external factors for robot tools within HRI. It was asked for which factors that was most relevant and how to design them to improve the human wellbeing. The questions were answered by 22 participants. Half of the group mentioned the importance of non-sharp design. Further also soft material was mentioned by five persons, as well as the benefit from human-looking design. Size, robust design and not complex design mentioned each by one person. The importance of a smooth movement in a good speed was by five respondents uttered, one reflected on the importance low noise and five persons of choice of colour.
In this chapter the results from earlier chapters are summarised and discussed, followed by the drawing of some conclusions.

6.1 Discussion

The research group consisted of mechanical engineering students that were not so well experienced in human robot interaction. Probably the results differed from what would have been collected if the group had consisted of robot operators. Nevertheless the majority of the respondents had seen an industrial robot within the last half a year and almost a third of the group had also experience from work either in environments with industrial robots or direct with robots.

The conditions for the study could also, with more resources, been better suited for the research. Ideally results would probably have been conceived if real robots or full-scale prototypes in existing industrial environments were repainted and if robot operators would have been asked to give response to whether the colour affects their psyche and how. The same procedure could then have been done also for robot tools, with a change of robot grippers in an interaction.

The results were in this study collected with a variant of the state-anxiety survey. Maybe a use of the trait-anxiety test as well would have been good. Then the individual results could have been normalised according to the individual general anxiety. That would eventually have given results with narrower distributions. Overall the anxiety for different colours and grippers to some part is a question of personal taste and probably also depending of factors like age, gender, nationality and more.

6.1.1 Colour Preferences

In accordance with the findings in the reference frame, the data collected from the questionnaire showed that red objects caused greater anxiety than blue objects; see Table 3 and Figure 19. The distribution distinguishes for some colours to significant degrees, at a significance level of 5 % between red and orange and 0.1 % between all blue-red, blue-orange and red-white. That means that orange and red objects caused a greater anxiety than blue, further also that red caused greater anxiety than both orange and white. This is assumed to be while blue and white are seen as calm colours, which was also reported in the reference frame.

When the colours were coupled to industrial robots the results slightly differed. Red was once again most anxiety causing, but only significant greater than orange and white. Blue was found to be second most anxiety causing followed by orange and white, see Table 6, Table 8 and Figure 21. Also the comparison between the two parts of the questionnaire shows that result, see Figure 24. The high anxiety rate for the blue robots could possibly be explained by the bright colour. The decrease of anxiety for orange when applied on robots can possibly have a connection to the tradition of orange robots in the industry, like standards by companies like ABB and KUKA. Just the fact that robots “shall” be orange can have influenced the results for the participants. Also the colour preference question gained the result that orange was most preferred, probably because of the reasons above.

Further it can be discussed whether the respondents answered and evaluated the colours on the robots after the aspect that they preferred the colour since it could be seen or since it made them calm. The statements can have been interpreted to have other meanings than they were meant to have. There exists a risk that for example the statements “losing concentration” and “getting distracted” were seen as synonyms and not as opposites as they were intended. The statement with “lose concentration” was taken under extra consideration, but even though, tests, for the general colour case, with both an exclusion and an inversion of the results from these statements...
only resulted in greater standard deviation for all colours and marginally changes in the mean anxiety for red and orange.

6.1.2 Preferences for Robot Grippers

The mean of the anxiety sum only differed slightly between the five robot grippers, only gripper one and two differed significant from each other regarding the distribution of anxiety sum. Even though, some differences could be observed. Table 10 shows that gripper one and four caused the greatest anxiety, when compared with the attributes from Table 2 it can be seen that the two grippers have in common that they both are constructed in angular shapes. Besides they are also defined as having sharp angels. But the effect from the sharp angels is supposed to be less distinct since the third gripper had lower mean of anxiety sum. A subject to discuss is also the other attributes that varied between the grippers. Both colour and material distinguished the grippers from each other. The respondents were asked not to pay regard thereon, but those characteristics could possibly also have an influence on the results. It is also supposed that a study with prototypes would have given different results, he anxiety sum would possibly have differed more in a physical study than the results from this study of pictures did.

The dependence of number of fingers on the grippers on the caused anxiety was also examined. A linear dependence was found with decreasing anxiety with an increase of number of gripper fingers.

It can be discussed whether the use of different robot grippers influences the grade of human anxiety. Probably the differences in anxiety sum would have differed more for a study in a real industrial environment. The personal taste seemed to have a great influence on the preference of the different grippers. For example, the robot hand, here called gripper nr 2, either was seen as frightening or trustful. Only when the participants were encouraged to place the grippers in order of preference, one robot gripper stood out from the other, the robot hand, see Figure 29.

6.2 Conclusion

Following conclusions have been drawn:

- White and orange coloured industrial robots cause lower anxiety than red and blue robots.
- Orange was the most preferred robot colour when the participants ranked the colours after preference.
- The robot hand was most preferred as robot gripper.
- A linear dependence for the anxiety caused by number of robot gripper fingers could be found.
- Colour seemed to cause greater distribution than the shapes of the robot grippers in mean value with clearer differences and better significance in the difference in mean anxiety sum from each other.
7 RECOMMENDATIONS AND FUTURE WORK

This chapter presents some recommendations for more detailed further studies and for future work.

7.1 Recommendations

The results gained from this bachelor project have resulted in the conclusion that robots used for human-robot interaction ideally shall be painted either white or orange. An application of this colour recommendation in the industry would probably result in a calmer work atmosphere for the employees that work in positions close to robots. Likewise also robot grippers can be constructed or chosen to reduce the human anxiety grade. Ways to do that can, according to earlier presented results, be done through the use of robot grippers with more fingers.

7.2 Future Work

Suggestions for future work would be more research on the human wellbeing in industrial environments. The study would be interesting to repeat after some years with deeper HRI developments in the industry. Would robot operators then be of another meaning?

Further would it also be of interest to deepen the study with more colours and also with different kind of robot tools, not just grippers. The study could also be extended with an investigation of the reason that cartoons mostly have four fingers and how innovative designs of robot grippers, like for example grippers made of rubber, influences the anxiety. It could also be interesting to study an application of household robots design in the industry.

The attributes that were mentioned as factors that could influence the grade of anxiety also spoke for a study with prototypes. Influences of both size and material are supposed to be easier to value for real objects than from pictures. The results would probably be even better with a use of full-scale prototypes.


Questionnaire – Feelings for colour and shape

This questionnaire is used as research for my bachelor thesis and is focused on the field of Human-Robot Interaction (HRI). The purpose of this survey is to collect information about preference of colour on industrial robots and shapes of commonly used robot tools.

Instructions: Mark your answer like this: ☐

“Unmark” a box like this: ■

Thank you for participating,

Caroline Lindberg

Part 1: General questions

1. Gender
   - Male ☐
   - Female ☐

2. Age [years]
   - 11-29 ☐
   - 30-44 ☐
   - 45-59 ☐
   - 60 + ☐

3. Occupation
   - Student ☐
   - PhD ☐
   - Employed ☐
   - Other ☐

4. Experience from Human-Robot interaction
   - None ☐
   - Minimal ☐
   - Moderate ☐
   - High ☐

5. Experience from environments with industrial robots
   - None ☐
   - Minimal ☐
   - Moderate ☐
   - High ☐

6. When did you last see a robot of any kind in person?
   - Within the last week ☐
   - Within the last month ☐
   - Within the last half a year ☐
   - Within the last year ☐
   - More than one year ago ☐
   - Never ☐

7. When did you last see an industrial robot in person?
   - Within the last week ☐
   - Within the last month ☐
   - Within the last half a year ☐
   - Within the last year ☐
   - More than one year ago ☐
   - Never ☐

8. What was the situation? You can mark more than one alternative.
   - In direct cooperation with a robot ☐
   - In work in an industrial environment including robots ☐
   - During a facility tour/visit ☐
   - Other situation: ____________________________ ☐

Part 2: General colour cases

In this part of the questionnaire, some objects are given. Every group of objects has the colour in common, but in different nuances. Look at the objects and imagine yourself in an environment dominated by that colour. You have to stay in this environment for a long period of time. Read each statement and respond by marking your answer as the alternative that describes your opinion the best.

1. The first objects under consideration are blue. As described above, you are for a long time in an environment dominated by this colour. Respond with the statements below.

   - Not at all ☐
   - Somewhat ☐
   - Moderately so ☐
   - Very much so ☐

   a. This colour reminds me of stressful feelings.

b. This colour reminds me of comfort.

c. This colour reminds me of feelings of calm.

d. This colour reminds me of feelings of nervousness.

2. I would get distracted while working surrounded by this colour for a long time.

3. I would lose concentration while working surrounded by this colour for a long time.

2. The second colour in this experiment is red. See the objects below and please respond to the statements given the situation as above.

   - Not at all ☐
   - Somewhat ☐
   - Moderately so ☐
   - Very much so ☐

   a. This colour reminds me of stressful feelings.

b. This colour reminds me of feelings of calm.

c. This colour reminds me of feelings of nervousness.

d. This colour reminds me of comfort.

2. I would get distracted while working surrounded by this colour for a long time.

3. I would lose concentration while working surrounded by this colour for a long time.
3. Also for the orange objects, respond to the statements below.

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Somewhat</th>
<th>Moderately so</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I would lose concentration while working surrounded by this colour for a long time.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. This colour reminds me of feelings of calm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. This colour reminds me of comfort.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. This colour reminds me of feelings of nervousness.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. This colour reminds me of stressful feelings.</td>
<td></td>
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<td></td>
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<tr>
<td>f. I would get distracted while working surrounded by this colour for a long time.</td>
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</tbody>
</table>

4. The last colour under consideration is white. Look at the objects below and respond to the statements below.

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Somewhat</th>
<th>Moderately so</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. This colour reminds me of comfort.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. I would get distracted while working surrounded by this colour for a long time.</td>
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<td></td>
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</tr>
<tr>
<td>c. This colour reminds me of stressful feelings.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. This colour reminds me of feelings of nervousness.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>e. I would lose concentration while working surrounded by this colour for a long time.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. This colour reminds me of feelings of calm.</td>
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</tbody>
</table>

**Part 3: Connection to Human-Robot Interaction**

In this section some pictures of robots are shown. Imagine yourself at work in a factory, in close cooperation with an industrial robot. You are required to work in close proximity to the robot for several hours. Look at the robots and use the colour nuance as the attribute in common for the robots when responding to the following statements. Read each statement and mark the alternative that best describes your opinion.

5. The first robots under consideration are orange. Use the statements to describe how you would feel in the case given above.

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Somewhat</th>
<th>Moderately so</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. With a robot painted like that, I think I would feel distracted from my task.</td>
<td></td>
<td></td>
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<tr>
<td>b. With a robot painted like that, I think I would feel stressed.</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. With robots painted in this colour, I think I would feel comfortable.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. With robots painted in this colour, I think I would feel in danger.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. When the robots are painted like that, I think I would lose the concentration for my task.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. When the robots are painted like that, I think I would feel nervous.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. When the robots are painted like that, I think I would feel calm.</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>h. With robots painted in this colour, I think I would feel safe.</td>
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</tbody>
</table>
6. Now please repeat the exercise with red robots. As above, you are working together with the robot for a long time. Use the statements to respond how you would feel.

   ![Red robots]

   a. When the robots are painted like that, I think I would feel nervous. ☐ ☐ ☐ ☐
   b. With robots painted in this colour, I think I would feel comfortable. ☐ ☐ ☐ ☐
   c. When the robots are painted like that, I think I would lose the concentration for my task. ☐ ☐ ☐ ☐
   d. With a robot painted like that, I think I would feel distracted from my task. ☐ ☐ ☐ ☐
   e. With a robot painted like that, I think I would feel stressed. ☐ ☐ ☐ ☐
   f. With robots painted in this colour, I think I would feel in danger. ☐ ☐ ☐ ☐
   g. With robots painted in this colour, I think I would feel safe. ☐ ☐ ☐ ☐
   h. When the robots are painted like that, I think I would feel calm. ☐ ☐ ☐ ☐

7. Here white robots are shown. Use the pictures to give answers to the statements below. As before, you are working together with the robot for a long time.

   ![White robots]

   a. With robots painted in this colour, I think I would feel in danger. ☐ ☐ ☐ ☐
   b. With robots painted in this colour, I think I would feel comfortable. ☐ ☐ ☐ ☐
   c. When the robots are painted like that, I think I would feel calm. ☐ ☐ ☐ ☐
   d. With a robot painted like that, I think I would feel distracted from my task. ☐ ☐ ☐ ☐
   e. With a robot painted like that, I think I would feel stressed. ☐ ☐ ☐ ☐
   f. When the robots are painted like that, I think I would lose the concentration for my task. ☐ ☐ ☐ ☐
   g. With robots painted in this colour, I think I would feel safe. ☐ ☐ ☐ ☐
   h. When the robots are painted like that, I think I would feel nervous. ☐ ☐ ☐ ☐
8. Respond to the statements also for the blue painted robots. As before, you are working together with the robot for a long time.

| a. With a robot painted like that, I think I would feel stressed. | Not at all | Somewhat | Moderately | Very much so |
| b. When the robots are painted like that, I think I would feel distracted from my task. | Not at all | Somewhat | Moderately | Very much so |
| c. With a robot painted like that, I think I would feel calm. | Not at all | Somewhat | Moderately | Very much so |
| d. When the robots are painted like that, I think I would feel in danger. | Not at all | Somewhat | Moderately | Very much so |
| e. With robots painted in this colour, I think I would feel comfortable. | Not at all | Somewhat | Moderately | Very much so |
| f. With robots painted in this colour, I think I would feel safe. | Not at all | Somewhat | Moderately | Very much so |

9. Keep the same scenario in your mind; you are still working in a factory in close cooperation with a robot for a long time. Use the robot pictures above as a help. For every statement, grade from 1 to 4 which colour on the robot that does fulfill the statement the most, with 1 representing the best suited and 4 the least suited.

| a. I would feel most safe while working with… | i. an orange robot | iii. a white robot |
| b. I would feel most nervous while working with… | ii. a red robot | iv. a blue robot |
| c. I would have less concentration while working with… | i. an orange robot | iii. a white robot |
| d. I would feel most in danger while working with… | ii. a red robot | iv. a blue robot |
| e. I would feel most calm while working with… | i. an orange robot | iii. a white robot |
| f. I would feel most stressed while working with… | ii. a red robot | iv. a blue robot |
| g. I would feel most comfortable while working with… | i. an orange robot | iii. a white robot |
| h. I would be least distracted while working with… | ii. a red robot | iv. a blue robot |
| i. I would most prefer working with… | i. an orange robot | iii. a white robot |
| j. I would most not prefer working with… | ii. a red robot | iv. a blue robot |
Part 4: Robot tools

Below a series of pictures of robot grippers are shown. The grippers are usually placed at a robot’s end effector. Imagine yourself at work in a factory, where work close to the robot for several hours is necessary. Look at the grippers and its shape, and respond to the statements. Try to ignore differences in colour and material. Mark the alternative that describes your opinion the best.

10. Use the statements below and respond for the gripper nr 1, below. As described above, you are working for some hours with a robot using this tool.

Robot gripper nr 1.

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Somewhat</th>
<th>Moderately so</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I would feel in danger.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. I would feel nervous.</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>c. I would feel safe.</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>d. I would feel comfortable.</td>
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<td></td>
</tr>
<tr>
<td>e. I would lose concentration.</td>
<td></td>
<td></td>
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<tr>
<td>f. I would feel stressed.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. I would get distracted.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. I would feel calm.</td>
<td></td>
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</tbody>
</table>

11. Look at gripper nr 2 and respond to the statements for the situation given above.

Robot gripper nr 2.

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Somewhat</th>
<th>Moderately so</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I would feel calm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. I would lose concentration.</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>c. I would get distracted.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>d. I would feel comfortable.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. I would feel nervous.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. I would feel stressed.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. I would feel safe.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. I would feel in danger.</td>
<td></td>
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</tbody>
</table>

12. Look at gripper nr 3 and respond to the statements for the situation given below.

Robot gripper nr 3.

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Somewhat</th>
<th>Moderately so</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I would lose concentration.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. I would get distracted.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>c. I would feel in danger.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. I would feel nervous.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>e. I would feel stressed.</td>
<td></td>
<td></td>
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<tr>
<td>f. I would feel safe.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. I would feel calm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. I would feel comfortable.</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

13. Look at gripper nr 4 and respond to the statements for the situation given below.

Robot gripper nr 4.

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Somewhat</th>
<th>Moderately so</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I would feel in danger.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. I would feel comfortable.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. I would lose concentration.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. I would feel nervous.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. I would feel safe.</td>
<td></td>
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</tr>
<tr>
<td>f. I would feel stressed.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. I would feel calm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. I would get distracted.</td>
<td></td>
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</tbody>
</table>
14. Look at this gripper, nr 5, and respond to the statements for the situation given below.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Not at all</th>
<th>Somewhat so</th>
<th>Moderately so</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I would feel comfortable.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. I would feel in danger.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>c. I would get distracted.</td>
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</tr>
<tr>
<td>d. I would feel safe.</td>
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</tr>
<tr>
<td>e. I would lose concentration.</td>
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<tr>
<td>f. I would feel stressed.</td>
<td></td>
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<td></td>
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<tr>
<td>g. I would feel calm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. I would feel nervous.</td>
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</tbody>
</table>

15. Imagine the same situation, as in questions 10 to 14; you are still working in a HRI situation close to a robot using one of the robot grippers. Grade from 1 to 5 (where 1 means the best) which robot gripper that best suites the statements below.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Image 1</th>
<th>Image 2</th>
<th>Image 3</th>
<th>Image 4</th>
<th>Image 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
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<tr>
<td>3.</td>
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- a. I would feel most calm while working with…
  i. robot gripper nr 1. iv. robot gripper nr 4. 
  ii. robot gripper nr 2. v. robot gripper nr 5. 
  iii. robot gripper nr 3. 

- b. I would be least concentrated while working with…
  i. robot gripper nr 1. iv. robot gripper nr 4. 
  ii. robot gripper nr 2. v. robot gripper nr 5. 
  iii. robot gripper nr 3. 

- c. I would feel most stressed while working with…
  i. robot gripper nr 1. iv. robot gripper nr 4. 
  ii. robot gripper nr 2. v. robot gripper nr 5. 
  iii. robot gripper nr 3. 

- d. I would feel most comfortable while working with…
  i. robot gripper nr 1. iv. robot gripper nr 4. 
  ii. robot gripper nr 2. v. robot gripper nr 5. 
  iii. robot gripper nr 3. 

- e. I would feel most nervous while working with…
  i. robot gripper nr 1. iv. robot gripper nr 4. 
  ii. robot gripper nr 2. v. robot gripper nr 5. 
  iii. robot gripper nr 3. 

- f. I would be least distracted while working with…
  i. robot gripper nr 1. iv. robot gripper nr 4. 
  ii. robot gripper nr 2. v. robot gripper nr 5. 
  iii. robot gripper nr 3. 

- g. I would be most safe while working with…
  i. robot gripper nr 1. iv. robot gripper nr 4. 
  ii. robot gripper nr 2. v. robot gripper nr 5. 
  iii. robot gripper nr 3. 

- h. I would feel most in danger while working with…
  i. robot gripper nr 1. iv. robot gripper nr 4. 
  ii. robot gripper nr 2. v. robot gripper nr 5. 
  iii. robot gripper nr 3. 

- i. I would most prefer working with …
  i. robot gripper nr 1. iv. robot gripper nr 4. 
  ii. robot gripper nr 2. v. robot gripper nr 5. 
  iii. robot gripper nr 3. 

11 (13) 12 (13)
Part 5: Comments

16. How do you feel about the four colours mentioned in this questionnaire, orange, red, white and blue, as robot paint?

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__________________________________________________________________________

17. To feel comfortable, which colour would you prefer as paint on an industrial robot in a HRI situation, and why?

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

18. Which other external factors, like shape, colour and material, for a robot tool do you think are the most relevant for HRI?

__________________________________________________________________________

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__________________________________________________________________________

19. How do you think the attributes that you mentioned in question 18 shall be designed and chosen to improve the human wellbeing?

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__________________________________________________________________________