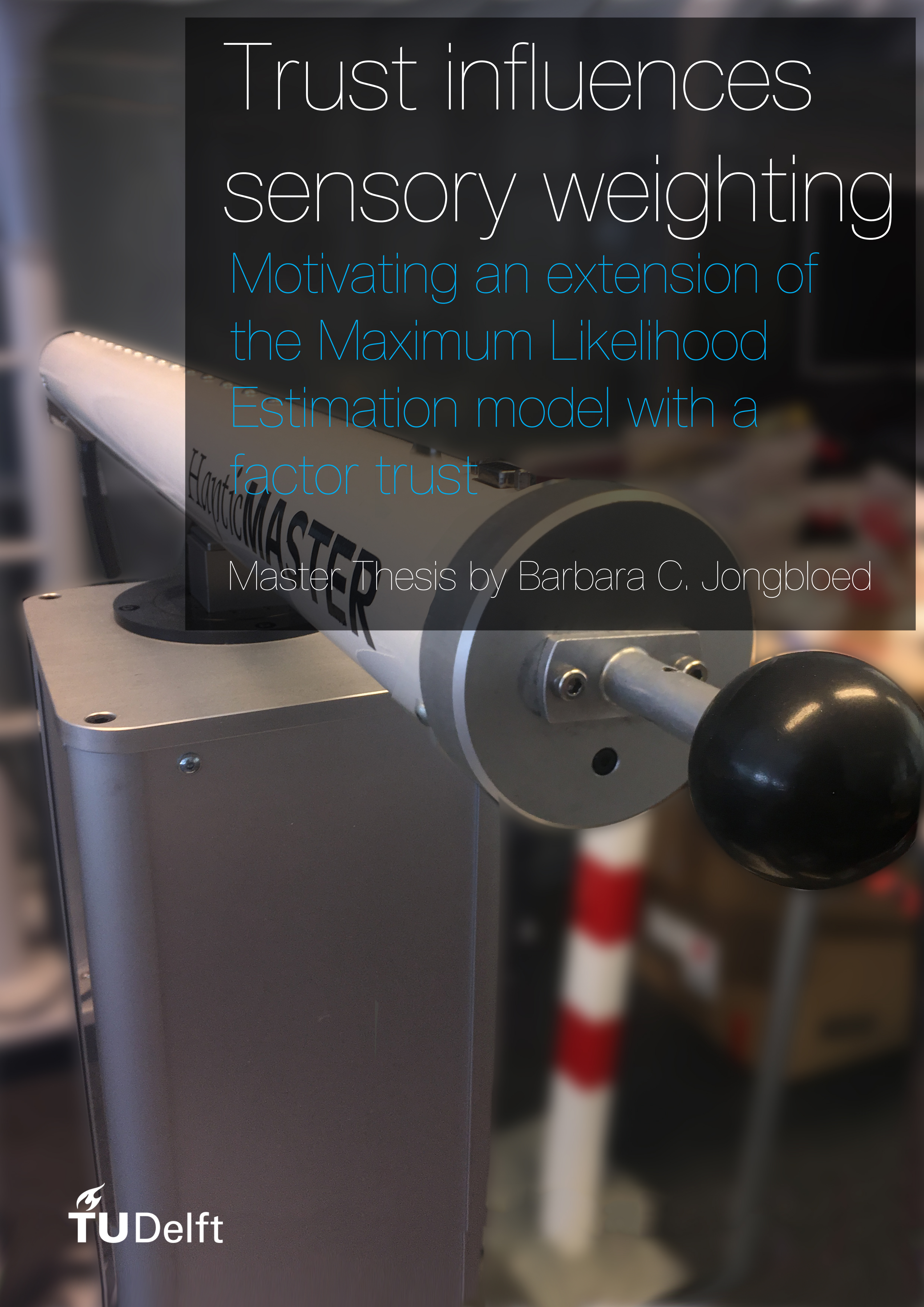

Trust influences sensory weighting

Motivating an extension of the Maximum Likelihood Estimation model with a factor trust

Master Thesis by Barbara C. Jongbloed

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Trust influences sensory weighting

Motivating an extension of the Maximum Likelihood Estimation model with a factor trust

by

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ABSTRACT

There is a distinction between environmental and social interactions as humans interpret the world. Environmental interactions are based on weighted sensory estimates formed on integrated redundant information. Trust is a heuristic used in social interactions. As social interactions and technology interrelate, social factors become influences on the environmental estimates. Hence trust could influence our sensory estimates.

The optimal sensory weights for the sensory estimates are determined with a Maximum Likelihood Estimate based on the reliability of the sensory information.

The objective of this research is to find evidence that trust influences sensory weighting on the level of sensory integration, believing that human-machine interaction will benefit from a better understanding of sensory weighting.

We hypothesised that information on the reliabilities of the sensory cues, while not changing these, will cause participants to reweigh the sensory information. Reweighing sensory information when the reliability of the sensory cue has not changed contradicts the Maximum Likelihood Estimation prediction.

An experiment was conducted in which participants performed a target-hitting task with a haptic device. The target was hidden, yet participants were presented with a visual and haptic cue to deduct the location of the target. Although both cues were not of equal reliability, the participants created the optimal sensory estimate by sensory integration.

The results showed that trust influenced sensory weighting. Since the outcome of the Maximum Likelihood Estimation model was challenged by the occurrence of sensory reweighting because of trust, it is recommended to extend the model with a factor trust.

1

INTRODUCTION

Throughout life, humans accumulate knowledge of situations and circumstances. The collected knowledge is used to form an estimate of the surrounding and gives handholds how to interact with this surrounding. A precept based on our senses is called a sensory estimate. Parallel to the sensory estimate, we have social interactions.

Trust is a mechanism that plays a role in human interactions [7]. As our interactions extend from human to human interactions to human-machine interactions, there is a reason to believe that a social aspect also comes along in human-machine interactions, since humans respond socially to technology [18].

Trust supports interactions by providing heuristics for uncertainties one might have regarding the interaction. These uncertainties come forth from the complex dynamics communication induces between humans, but the same is true for human-machine interactions. One has to reckon with all possible outcomes for all parties involved while also anticipating for unforeseen events [19].

There is a distinction between interactions with our environment and social interactions. The interpretation of the environment is based on sensory information forming a sensory estimate, for social interactions trust is used.

In current society, social and environmental aspects interrelate as we shift our social interactions towards technology. As the lines become blurred between social and environmental interactions due to human-machine interaction, there is cause to believe that social interactions influence the environmental interactions. Hence trust influences our sensory estimate.

Sensory estimates are based on sensory information and prior knowledge. Increased reliability of the sensory estimate is acquired through sensory integration, the process of integrating redundant information from multiple senses. Sensory integration optimises to the least amount of noise by weighing the sensory information from the various sensory modalities, called sensory weighting [8].

Typically sensory integration is modelled with a Maximum Likelihood Estimation (MLE) model. In MLE the individual estimates are assumed to contain Gaussian noise that is independent of each other [8, 15]. The MLE implies that the individual estimates are combined to a weighted average [8, 15, 29]. The weights of the individual estimates are the inverse of the variances of the sensory estimates resulting in the optimal weighing of the sensory information [8, 9, 13, 15, 29].

According to the MLE model no other factor than noise influences sensory weighting, making sensory weighting based on the reliabilities of the sensory information [29]. The influence of human factors, such as trust between operator and system, has therefore not been considered or examined in other research. Hence this research is novel for combining two factors, trust and sensory weighting, from two disciplines, neuroscience and human factors.

Knowing if trust influences sensory weighting is essential as trust affects our view of designing human-machine interactions. From the introduction of automated systems, automation has found its way into almost all human activities [10]. Since the mid-1960s we tried to optimise human-machine interaction [30]. Instead of interaction, the operator was placed out of the control loop to a supervisory role. Humans make inadequate supervisors as they are not able to focus more than 30 minutes on an environment where almost nothing happens [6]. Therefore optimising the human-machine interaction is necessary.

It is expected that by better understanding the influence of trust on sensory weighting on the level of sensory integration human-machine interaction will benefit. The goal of this research was to provide evidence whether or not trust influences sensory weighting.

For analysing the influence of trust on sensory weighting a definition of trust has to be defined as no strict definition of trust can be found in literature [5]. Three components in trust definitions were most repeated across multiple definitions, see Appendix A.1. The three components are: multiple interacting entities, a constructive behaviour towards what or whom is to be trusted and an action supporting the constructive behaviour. Also, multiple factors were identified on how to create trust. The three most common factors are (system) performance, predictability and dependability [17, 27, 28]. System performance relates to trust in that a proper working system creates trust. Predictability requires a system to respond as expected. Operators will still trust a system even if it gives an unwanted response as long as the response was expected by the operator. An intuitive example is when driving a car on snow, that the car slips is an unwanted response of the system yet an expected one. Dependability strongly relates to predictability as a predictable system also makes a more dependable system. Dependability further relates to the amount of supervision the system needs. A dependable system needs less frequent checks on the system's performance [24], making the operator trust the system more. As situations or tasks change, the reliability, dependability and predictability also change between system and operator, likewise changing the trust of the operator in the system. The ever-changing nature of trust makes trust a dynamic and a hard to describe characteristic.

Together the creating factors for trust (system performance, predictability and dependability), and the building blocks for the different definitions of trust (multiple interacting entities, a constructive behaviour towards what or whom is to be trusted and an action supporting the constructive behaviour), form the definition that will be used throughout this report. Trust is an assurance for expectancies between at least two parties within a common goal.

The system used in this research for investigating the influence of trust on sensory weighting is a haptic shared control system. In haptic shared control, the haptic sense is used on the interface between the controller and the operator. The haptic shared control system determines the optimal control strategy, though the operator is also obliged to provide a continuous input. As the operator is kept in the control loop, haptic shared control is less sensitive to the pitfalls of automation, such as skill degradation, unbalanced mental workload and loss of situational awareness [4, 22]. More importantly, the operator can overrule the system in an unexpected situation [25]. In case that a haptic shared control system is used to support another sense the information communicated to the operator is redundant. Redundant information is integrated by the brain to increase the reliability of the sensory estimate as sensory integration reduces variance [8]. An example of a haptic shared control loop is illustrated in Figure 1.1

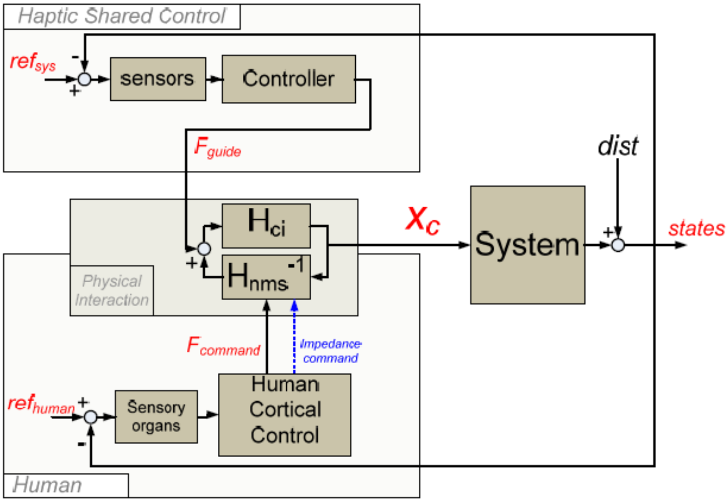

Figure 1.1: A representation of a haptic shared control scheme. The operator and the haptic shared control system interact with each other with a force, F_{guide}, through the control interface (H_{ci}) and a force $F_{command}$ on the neuromuscular system of the human (H_{nms}) resulting in a position X_c, steering angle. Obtained from Abbink and Mulder [3]

From the research of Gibo et al. [9] was learned that humans trust augmented cues in the form of haptic assistance, and integrated augmented cues in the same way as natural cues. Furthermore, humans were able to optimise performance even when the assistance contained generated trial-by-trial errors. These errors were introduced by Gibo et al. [9] to simulate assistance of realistic applications were the errors could be induced by the sensors or model generating the assistance [9].

Knowing if trust influences sensory weighting is essential in the development of an intelligent assisting system if we want to design a properly working system. Systems that are not trusted can lead to disuse and misuse of that system, despite working correctly [25, 27]. Furthermore, the influence of trust on sensory weighting will also influence the operator's performance. So to optimise the operator's performance trusting the system is necessary.

As humans react socially to technology [18] and therefore human-machine interactions we believe that trust influences sensory weighting. Leading to the research question: Does trust influence sensory (re)weighting when working with a haptic shared control device?

The influence of trust on sensory weighting was assessed with an experiment designed on the research and experimental protocol of Gibo et al. [9]. As a haptic shared control system combined with a visual input is a context in which two senses are integrated, participants should optimise their sensory estimate following a MLE strategy [29].

We hypothesise that information regarding the reliance of the sensory cues, while not changing the reliabilities, will let participants reweigh the sensory information. Participants will try to compensate for the trust factor, influencing the participant's reliance on the sensory cues. Therefore trust will lead to a reweighting of the sensory information. Reweighing the sensory information when the reliability of the sensory cues has not changed disputes the MLE prediction, as the MLE model only includes the influence of the reliabilities.

2

MATERIALS AND METHODS

2.1. PARTICIPANTS

Eleven participants, (all female; 10 right-, 1 left-handed; age 25.7 ± 0.95 yrs). The experiment was approved by the Ethics Committee For Human Research of the Delft University of Technology. All participants gave informed consent before participating in the experiment.

2.2. EXPERIMENTAL SETUP

For reaching movements in the horizontal plane, the participants held the HapticMaster with their dominant hand. The movements of the HapticMaster were recorded at 1000 Hz by a controller from Bachmann electronic GmbH. Approximately 140 cm in front of the participant a monitor (88.5×50.0 cm) presented the visual cues and cursor. The cursor visualised hand movements made with the HapticMaster. The HapticMaster provided the haptic cue. The experimental setup is illustrated in Figure 2.1.

2.3. TASK

The participants were instructed to make a fluid motion with the HapticMaster to reach a hidden target. Participants deducted the target position with the visual and haptic cue. The target was located on an invisible curved line with a span of 90° and a varying radius between 10 and 30 cm, illustrated in Figure 2.1.1. To start a trial, the participants had to bring the cursor to the start position and hold still for 0.8s, after 0.8s the visual cue appeared, which marked the start of the trial, Figure 2.1.2. The haptic guidance was felt after the participant left the start position, and no cue for the haptic guidance was visible on the monitor. The trial stopped automatically when the participant travelled the distance of the x or y coordinate between the starting position and the target, Figure 2.1. At the end of each trial, the location of the target and the score for the trial were shown to give participants feedback on their estimated target location. A personal averaged score over the finished trials was visible the entire time of the session. The aim for the participants was to get their score as high as possible. The score was based on the absolute distance between the cursor and the target position, with a maximum score of 100 when the error was 0 cm and a minimum score of 0 for an error equal or above 2.0 cm [9].

The movement with the HapticMaster within a trial had to be made in 1000-2500ms. The time constraint prevented participants from making random or exploratory movements, but also restricted perceptual decision-making [9, 26]. Participants were notified during the trial of their performance by messages on the screen informing the participants if they moved too fast, too slow or stopped moving.

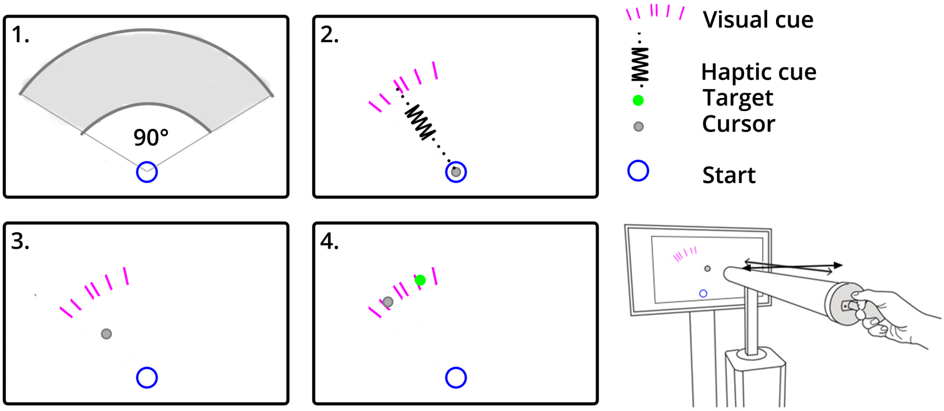

Figure 2.1: Rectangle 1-4 shows the different stages of the task, the image in the right bottom corner is an impression of the experimental setup. 1. The grey area indicated the area where a target was drawn; this was not visible to the participant. 2. When the cursor was in the start location for 0.8s the visual and haptic cue were generated. The visual cue was shown on the screen, and the guiding force was felt after leaving start. 3. The participant travelled to the hidden target. 4. The end of a trial, the target was shown.

2.4. DESIGN VISUAL AND HAPTIC CUES

The objective for the participants was to move towards a hidden target, using a visual and haptic cue. The position of the target was drawn from a normal distribution on a span of 90°, between a 45° angle and a 135° angle. The location of the visual and the haptic cue are called visual and haptic centroid respectively. The visual cue consists of six pink stripes around the visual centroid. The visual centroid was drawn from a normal distribution with a standard deviation of ± 1.0 cm around the target. The haptic cue was presented by the HapticMaster, in the form of a guiding force. The haptic cue contained trial-by-trial random errors with zero mean [9] and had a standard deviation of ± 0.8 cm around the target. As the uncertainty caused by the trial-by-trial errors cannot be estimated in one trial, it will not affect the reliability of the haptic cue [8, 9, 29]. Due to the zero mean of the error, the error was determined by the standard deviation ($\sigma_h = 0.8$ cm.

The reliability of the haptic and visual cue the participants received was based on the values of Gibo et al. [9] and the given ratio for reliability's of [0.5-2.0] given by Rohde et al. [29]. Resulting in a ratio of 1.25 between the reliabilities of the haptic and visual cue.

The haptic cue was generated with two linear springs, one in the x-direction and one in the y-direction, between the haptic centroid and the cursor. The springs that generated the force had a stiffness of k = *20 N/m* for the distance ΔX_{dis} between the haptic centroid and cursor resulting in the guiding force F_{lin}, as stated in the generalized Equation 2.1. For participant safety, the force of the linear springs was capped at 5N.

$$F_{lin} = k\Delta X_{dis} \tag{2.1}$$

From the reliabilities of the haptic and visual cue, the optimal sensory weights were determined with the Maximum Likelihood Estimation (MLE) model. The MLE model is based on Equation 2.2, with θ_v and θ_h being the location of the visual and haptic centroid. The weight factors, w_v and w_h the visual and haptic weight, were derived from Equation 2.3 as the weight factor is the proportional inverse of the respective variances (σ_v^2, σ_h^2). Both experimental sessions had as optimal weights w_v = 0.3902 and w_h = 0.6098, obtained with the MLE model and is illustrated in Figure 2.2. The weight of the visual cue was determined by the slope of the regression line based on the distance between the visual centroid to haptic centroid against the distance of the bimodal sensory estimate to the haptic centroid. When w_v =1 the regression line in Figure 2.2 followed the dotted diagonal line. Is w_v = 0 the regression line lies on the dotted horizontal line.

$$E_{bi,PR} = w_v\theta_v + w_h\theta_h \tag{2.2}$$

$$w_v = \frac{1/\sigma_v^2}{(1/\sigma_v^2 + 1/\sigma_h^2)}, w_h = \frac{1/\sigma_h^2}{(1/\sigma_v^2 + 1/\sigma_h^2)} \tag{2.3}$$

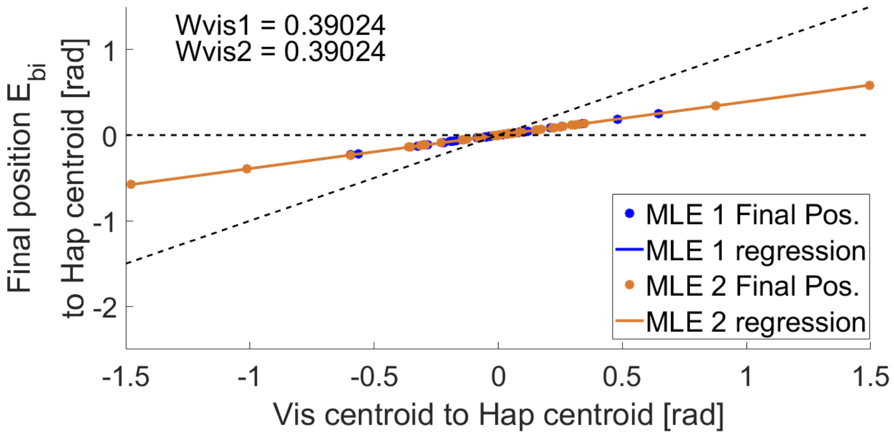

Figure 2.2: Weight on the visual cue according the MLE prediction, w$_v$ = 0.39. The dotted diagonal line indicates exclusive reliance on the visual cue w$_v$ = 1.00 the dotted horizontal line shows exclusive reliance on the haptic cue [9], w$_v$ = 0.00.

2.5. EXPERIMENTAL PROTOCOL

The experimental protocol was based on the paper "Trust in haptic assistance: weighting visual and haptic cues based on error history" by Gibo et al. [9]. The protocols were similar in that this protocol has the same structure as the protocol of Gibo et al. [9], a familiarisation block followed by experimental blocks. Furthermore, this protocol also included trial-by-trial errors in the haptic cue, to simulate the realistic performance of an assisting system [9]. The protocols were not alike in the number of trials. This protocol contained fewer trials per block and one experimental condition. Additionally, the time constraint was adapted to the area from which the target could be drawn. The time constraint prevented participants making perceptual decisions and random or exploratory movements. Perceptual decisions, random and exploratory movements were unwanted as they influenced the sensory weighting. Perceptual decisions are made when participants collect enough noisy sensory data to form a well informed decision[12], thereby changing their initial weighting of the sensory information. Exploratory or random movements are not focused on the task at hand resulting in a sensory weighting not related to the task.

Subjects performed in three sessions of trials, the first session was a training session, followed by two experimental sessions. The training session consisted of 25 trials, the experimental sessions each contained 50 trials as illustrated in Figure 2.3. After each experimental session, participants were asked to fill out a trust survey from Jian et al. [16]. The participants were also provided with a list explaining the various terms in the survey in English, see Appendix C, which ensured that all participants used the same definitions of the terms. Before the start of the second experimental session, participants were informed that the haptic guidance would be less reliable, though the reliability of both cues was constant through all sessions. The haptic cue had a reliability of $\sigma_h = 0.8$ cm and $\sigma_v = 1.0$ cm was the reliability of the visual cue.

The survey the participants filled out after an experimental session comprised of 12 statements that needed to be rated on a scale of 1 to 7; 1 = not at all- 7 = extremely agreeing with the statement. The participants were required to take a break after each session to avoid boredom and fatigue [9, 29].

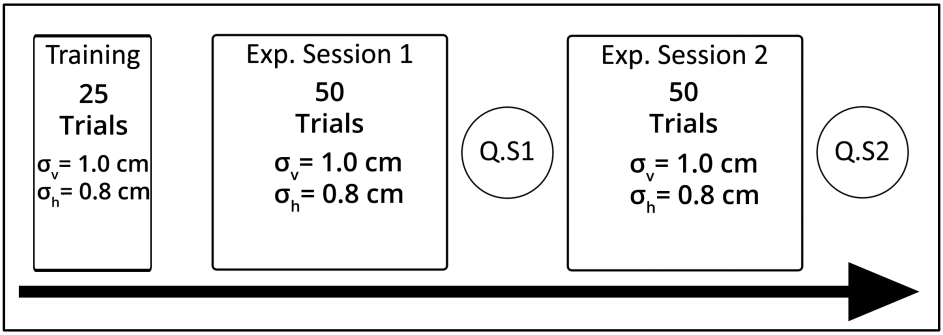

Figure 2.3: An overview of the experimental protocol. Participants performed in three sessions indicated with the rectangles, one training sessions and two experimental sessions. Reliabilities of the training and experimental sessions were $\sigma_v = 1.0$ cm for the visual cue and $\sigma_h = 0.8$ for the haptic cue. After each experimental session, participants were asked to fill out a survey on trust in the received haptic guidance, indicated with the circles Q.S1 and Q.S2. Participants were informed of a decrease in reliability of the haptic cue after QS.1.

2.6. DATA ANALYSIS

Participants learned to make movements within the time window in the training session. Some participants repeatedly braked just before the automatic stop. These self-braked trials were often marked as "too slow" instead of "don't stop moving". Omitting the self-braked trials was unjust as the trials were neither the result of perceptual decision making, random or exploratory movements. Therefore all trials were included in the data analysis.

The sensory weight distribution of the participants was calculated to determine sensory reweighting. The sensory weight distribution between the visual and haptic cue was determined with a linear regression analysis, Equation 2.4, based on Gibo et al. [9]. The angle between the participant's final position θ_p and the haptic centroid θ_h was given by Y. The angle between the visual centroid θ_v and the haptic centroid was given by Y. The slope of the regression line between X and Y indicated the value of the visual weight.

Sensory reweighting was confirmed by comparing the value of visual weight from experimental session one and two with a sampled paired t-test.

$$\begin{gathered} Y = a_0 + a_1 X \\ Y = \theta_p - \theta_h \quad [rad] \\ X = \theta_v - \theta_h \quad [rad] \end{gathered} \tag{2.4}$$

The results from the trust survey were analysed by comparing the scores from the first and second experimental session. As statements 1 to 5 were about distrusting the system and statements, 6 to 12 were concerning trusting the system the scale needed to be inverted for statements 6 to 12 to calculate a total score. A score of 12 indicated complete trust, a score of 84 complete distrust. The cumulative scores of the participants were compared with a paired sampled t-test to test for a significant change in trust.

Lastly, the correlation between trust and sensory reweighting was analysed with a Pearson correlation test. The correlation indicated whether a change in trust caused sensory reweighting. The values for trust were linearly normalised from a scale of 12 to 84 to a scale of 0 to 1 to compare better against change in visual weight. The change in trust ($\Delta trust$)and the change in visual weight (Δw_v) were determined with Equations 2.3, with $t1$ and $t2$ being trust for the first and second experimental session accordingly. The first and second value for visual weight are indicated with w_{v1} and w_{v2} respectively.

$$\begin{gathered} \Delta trust = t2 - t1 \\ \Delta w_v = w_{v2} - w_{v1} \end{gathered} \tag{2.3}$$

3

RESULTS

Participant 7 was excluded for technical reasons. All analyses were therefore performed on ten remaining participants.

3.1. SENSORY REWEIGHTING

3.1.1. VERIFYING SENSORY REWEIHTING

With a mean of $w_{v1} = 0.20 \pm 0.13$ standard deviation and $w_{v2} = 0.33 \pm 0.06$ standard deviation, (see Appendix E.1 for more details and descriptive statistics) a significant change in sensory weighting of the visual and haptic cue was found ($p = 0.042$), confirming sensory weighting.

Almost all participants relied initially more than expected on the haptic cue, compared to the optimal performance. The visual weight in experimental session one was lower compared to the MLE prediction of $w_v = 0.39$. When told that the haptic cue would be less reliable we saw an increased weight on the visual cue Figure 3.1, and Table 3.1 column two and three.

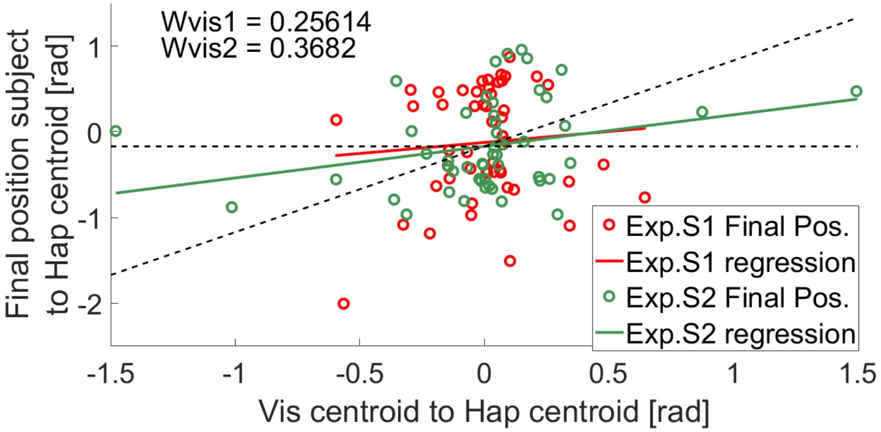

Figure 3.1: Weight on the visual cue increased in session two (green) compared to session one (red). The participant weighted the visual cue first $w_v = 0.26$ and in the second experimental session $w_v = 0.37$. The dotted horizontal line indicated complete haptic reliance $w_v = 0.00$, and the dotted diagonal line indicated complete visual reliance $w_v = 1.00$ [9].

3.1.2. PARTICIPANT PERFORMANCE

To see how participants performed over time the final position of the participant to the haptic centroid was plotted against the number of trials, and averaged for every ten trials as illustrated in Figure 3.2. The participant's position to the haptic centroid was corrected for the optimal distance to the haptic centroid. The values in Figures 3.2 and 3.3 indicated the space between the participant's final position and the optimal distance to the haptic centroid. A value of zero, therefore, indicated that the participant determined the perfect optimal distance to the haptic centroid. A value greater or smaller than zero indicated a larger distance to the optimal distance to the haptic centroid.

For all participants, except participant 3, the same effect was visible. Participants performed overall steady state in the first experimental session and performed exploratory in the second experimental session. Figure 3.2 shows the performance over time for a representative participant.

Participant 3 showed a change in performance in the first experimental session, which was not present in any of the other participant. In trials 20-29, the participant showed a greater distance to the haptic centroid, and the overcorrected in trials 30-39. From trial 40-50 the participant performed steady state.

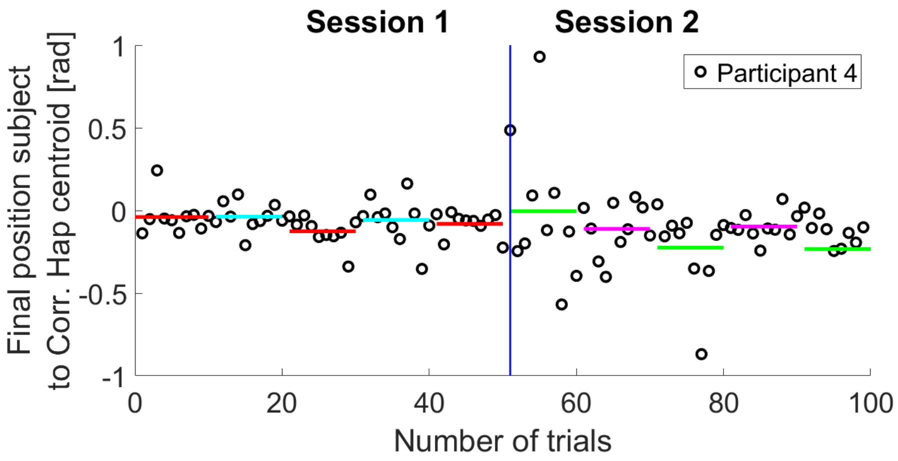

Figure 3.2: Performance of participant 4, the black circles indicate the corrected distance from the participant's position to the haptic centroid. The horizontal lines indicate the averaged distance per 10 trials, red and cyan for experimental session 1, green and pink for experimental session 2. The first experimental session showed a steady state performance apart from trial 30-39 (second red line) when an increase in distance to the optimal position to the haptic centroid appeared by all participants. From trial 40-50 participant's recovered to their former level. The second sessions showed varying averaged distances to the haptic centroid, indicating a continuously adapting performance.

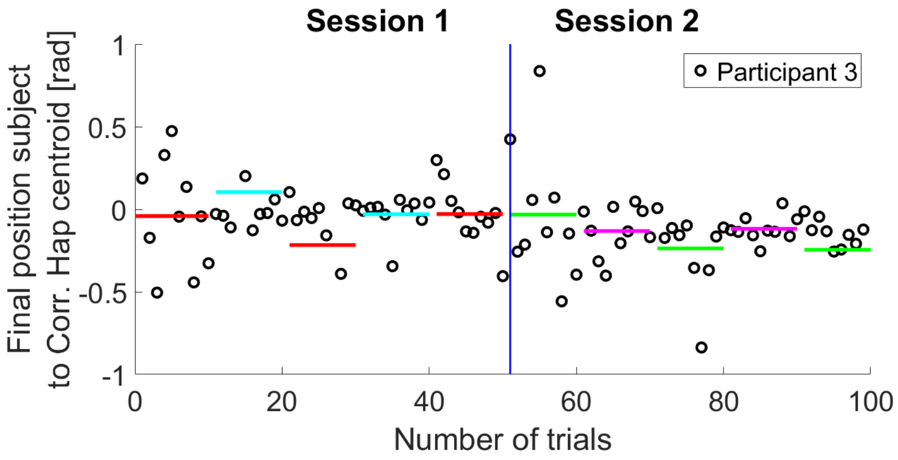

Figure 3.3: Performance of participant 4, the black circles indicated the corrected distance from the participant's position to the haptic centroid. The horizontal lines indicate the average distance per 10 trials, red and cyan for experimental session 1, green and pink for experimental session 2. The participant performed exploratory in both experimental sessions.

3.2. CHANGE IN TRUST

The paired samples t-test showed no significant change in the scores of trust after the first and second experimental session, see Appendix D.1. The scores of the participants are presented in Table 3.1, column four and five. The data from Table 3.1 column four and five, implied that most participants trusted the haptic guidance as they scored below the 48. The expected result was that participants trusted the haptic guidance less in the second experimental session and scored, therefore, higher in the second trust survey. Notwithstanding a non-significant change in trust, half the participants reacted as expected with a significant change in trust (p = 0.0480) which indicated that there might be a correlation between sensory reweighting and the trust score which was cancelled out in the survey.

3.3. CORRELATION BETWEEN TRUST AND REWEIGHTING

The correlation between trust and sensory reweighting was analysed by calculating the changes between experimental session one and two for the respective variables. Due to the linear distribution of data in Figure 3.4 a Pearson correlation was used and not a Spearman's rank order correlation, despite trust being on an ordinal scale. To overcome the ordinal scale of the trust survey, the trust scores were linearly normalised.

The data in Figure 3.4 has a mean of 0.06 [-] ± 0.18 [-] standard deviation. The magnitude of the Pearson correlation was 0.32, yet not significant (p = 0.3660) so no effect was found. Equation 3.1 shows that the p-value is strongly related to the number of participants [1], the number of participants is at which this result becomes significant is n = 40.

$$R = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \quad Following\ a\ T(n-2)\ distribution \tag{3.1}$$

If the result was significant, a correlation of 0.32 indicated a moderate positive correlation [14], between a change in trust and sensory reweighting, see Figure 3.4. Meaning that when the change in trust increased the change in weight on the visual cue also increased.

Data point (0.10[-],-0.38[-]) in Figure 3.4 has the appearance of an outlier yet did not comply with the value of ± 2.5 times the standard deviation (-0.38[-] against ± 0.45[-]) and was therefore not removed. If this point was removed, the magnitude of the correlation became 0.40 and would be significant at n = 25 increasing the relevance of the correlation. The cause of this outlier was participant behaviour, the change in trust was relatively large to the change in sensory weight compared to other participants.

Table 3.1 column six and seven showed the used magnitudes for the change of trust and the change in visual weight to calculate the correlation.

Based on Equation 2.3 the values of Δ trust are expected to be positive. A negative value for Δ trust indicated that trust increased in the second experimental session. For Δw_v also positive values were expected, the negative value for participant 3 indicated that the participant relied less on the visual cue in the second experimental session compared to the first experimental session.

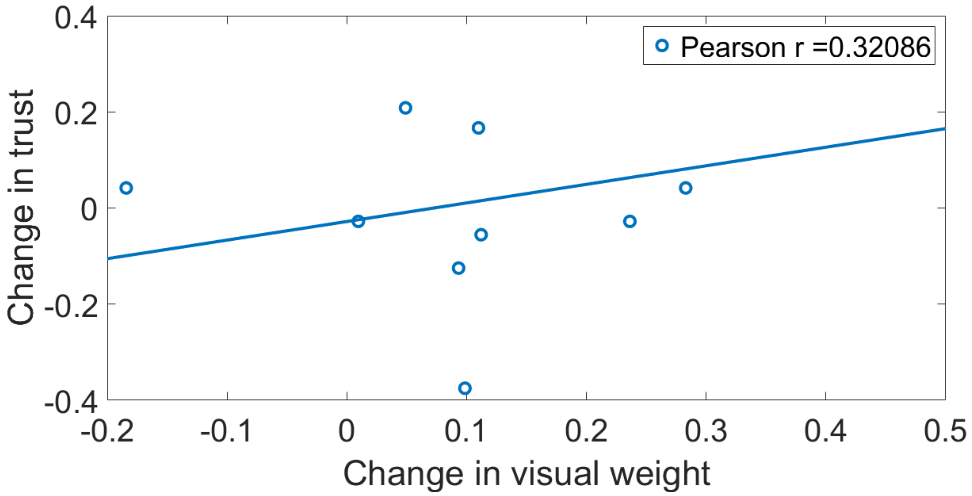

Figure 3.4: Correlation between the weight on the visual cue and trust, r = 0.32, p = 0.3667.

Table 3.1: Visual weight and trust scores for both experimental sessions in column two to four. Changes in trust and changes in visual weight between experimental session one and two are presented in cloumn six and seven. Changes in trust (column six) was linearly normalised.

Subject	w_v Exp. S1	w_v Exp. S2	Trust Exp. S1	Trust Exp. S2	Δ normalised trust	Δ w_v
1	0.0019	0.4248	30	55	0.3472	0.4229
2	0.0450	0.3279	35	38	0.0417	0.2829
3	0.4611	0.2769	21	24	0.0417	-0.1842
4	0.0905	0.3268	31	29	-0.0278	0.2363
5	0.2561	0.3682	38	34	-0.0556	0.1121
6	0.3073	0.3563	39	54	0.2083	0.0490
7	0.2505	0.3491	58	31	-0.3750	0.0986
8	0.2505	0.3491	28	40	0.1667	0.1099
9	0.1917	0.2013	46	44	-0.0278	0.0096
10	0.2324	0.3257	35.5	26.5	-0.1250	0.0933

4

DISCUSSION

4.1. SENSORY REWEIGHTING

Almost all participants weighted the visual cue below the MLE prediction in the first experimental session and reweighted in the second experimental session closer to the MLE prediction. One could argue that the suboptimal weighting in the first experimental sessions was caused by too few trials and that participants needed more practice to acquire an optimal estimate. As no structural change in performance within the first experimental session occurred, there is no suggestion of a learning effect. Results showed that participants performed steady state in the first experimental session.

Furthermore, all participants showed an increased in the distance to the haptic centroid in the first and second experimental session in trial 30-39 and corrected themselves only in the first experimental session to the level of early found steady state. The increased distance to the haptic centroid in both experimental sessions after 29 trials could indicate that participants were bored or fatigued.

In the second experimental session, an altered performance was visible. Participants kept changing their distance to the haptic centroid. The changing performance suggested that participants tried to reweigh the sensory information that corresponded to their trust perception. The altered distances to the haptic centroid lead to sensory reweighting.

Participant 3 was the only participant who relied more on the haptic cue in experimental session two. Examining the performance of participant 3 an inconsistent pattern was visible. The inconsistent pattern could be the result of too few trials or not having understood the task instructions. Not having understood the task instructions could result from her familiarity with the HapticMaster, as she also performed in another experiment that used the HaptiMaster. Performance of participant 3 in the second experimental session was in line with the performance of the other participants.

One could also argue that the sensory reweighting between experimental session one and two is caused by the influence of the task descriptions on the prior knowledge. If the task description influenced the prior knowledge, sensory reweighting occurred only in the first couple of trials followed by a learning effect that would cause the participants to perform steady-state again. Instead, we see participants reweighting the sensory cues in the second experimental session without achieving steady state. Not achieving steady state indicated that participants were still adapting to the sensory cues.

4.2. CHANGE IN TRUST

The not significant result for changes in trust could be caused by the fact that humans are poor estimators of trust [16]. Trust is a phenomenon influenced by performance, reliability and dependability [17, 27, 28]. System performance did not change throughout the experiment. Reliability and dependability increased in the training and first experimental session. In the second experimental session participant's were given a reason for decreased reliability and dependability, which was visible in the performance of the participants.

Since participant performance did change in the second experimental session, a change in trust perception was also expected.

Three factors could underlie the non-occurred change in trust, due to participant performance. Trust between humans and machines is created by openness, purpose, system performance and the focus of the trust. The purpose and system performance did not change, participants were still obliged to find the target, and the system still guided them in the direction of the target. There even was an increased openness since the participants were aware of the changed reliability of the haptic guidance. Furthermore, the information that the participants needed to trust, the haptic guidance, was presented in the same way, so there was also no change of focus.

Actively influencing the trust performance should be prevented in future experiments. It is, therefore, recommended to give altered scores in the second experimental session. The alteration could be that in the first experimental sessions participants received a score based on the distance to the target. In the second experimental session, the score is altered to the distance to the visual centroid. Expected is that participants will try to find the visual centroid instead of the target, and distrust the haptic guidance. The altered scores change the system performance in a manner that has no relation to sensory weighting, as the reliabilities of the presented cues stay the same. The altered scores cause conflict for the participant and forces implicit adaptation, resulting in a reweighting of the sensory input due to trust.

To analyse trust the survey from Jian et al. [16] was used. Though the survey was based on empirical research, it was not validated. Almost all participants had trouble identifying the trust statements in the haptic guidance. The difficulty of relating to the trust statements was perhaps due to low identification with the HapticMaster. An alternative reason could be that the survey was not sufficient enough to measure trust. Yet, as no other means of measuring trust was found, this survey is still recommended. Increased identification with the haptic guidance could be formed by adding human traits to the system [11]. The human traits should have the form of voice feedback instead of text printed on the screen.

4.3. EXPERIMENTAL LIMITATIONS

By actively informing the participants about the reliabilities of the presented cues the trust estimate of the participant was influenced. The participant expected unreliable behaviour. Consequently, the trust perception of the participant did not change. An experiment causing implicit adaptation of the sensory cues will prevent external influence on the trust estimate. Most likely participants will distrust the haptic guidance and also perceive distrust. When sensory reweighting occurs, and participants note a change of trust a correlation between trust and sensory weighting could be found.

A limitation of the designed guidance force caused almost all participants to stop moving during the trials. It was observed during the experimental sessions that participants developed over time a habit of braking just before the target was reached. The development over time could be explained by that participants learned that the target occurred half way of the height of the visual cue. When close to the target the guidance force was virtually undetectable, giving participants no stimulation to finish the trial. As these trials were not the result of exploratory movements or perceptual decision-making they did not influence the experimental results. Nonetheless, these trials were not distinguishable from unwanted trials, as the self-braking trials were recorded as too slow. Though unwanted behaviour was not observed, it was not testable. If perceptual decisions were made during the experiment, they influenced the sensory weighting. The same holds for exploratory movements. Therefore in future experiments, it is recommended to let the force decrease linearly up to a specific constant force to ensure participants finish the trial. Furthermore, changing the size and shape of the visual cue to the size and shape of the target will prevent participants learning at what height in the visual cue to expect the target.

Another point of improvement regarding the experimental protocol was the break after 50 trials. As a changed performance was observed in trials 30-39 in both experimental sessions. It is advised to let participants have a break after 30 trials instead of 50. Bored or fatigued participants are not focussed on the task at hand, which could lead to a suboptimal weighting of the task. A suboptimal weighting caused by boredom or fatigue distorts the results of the calculated sensory weights.

4.4. IMPLICATIONS FOR SOCIETY

A beginning in examining the influence of trust on sensory weighting has been made. This study shows that trust can influence the interpretation of the reliance of the sensory cues, which influences sensory weighting. It would be worth investigating if sensory reweighting occurs in an implicit adaptation study. If a significant change in sensory reweighting and a correlation between trust and sensory reweighting is found, we should consider how to apply this knowledge in the design of human-machine interaction.

Optimal human-machine interaction is not supervising the system. The supervisory role of the operator is not beneficial in the long run due to the pitfalls of automation. Haptic shared control is a potential solution for these pitfalls, but entering a human in a control loop also brings human errors. Therefore it is essential to assist the human as well as possible (e.g. by haptic guidance forces), by increasing the operator's trust in the system. Increasing trust in the system can be achieved by involving the operator in the process of system design. Involving the operator creates openness and a better understanding of the purpose and capabilities of the system.

5

CONCLUSION

The results showed a significant change in sensory weighting, confirming that the participants reweighted the sensory cues when their trust in the reliabilities of the presented sensory cues was influenced. That trust influenced sensory weighting has not been shown in any other research as no other research combines neuroscience and human factors. This research provides evidence that MLE theory alone is not sufficient to map human sensory weighting. If in follow-up studies the same result is found, MLE should be extended to incorporate a factor trust.

As social interactions and environmental interactions come together in human-machine interactions, it essential to consider trust in human-machine interactions. Humans use trust and sensory cues to find the optimal sensory weights. To assist the operator's performance with haptic guidance, one should take the influence of trust on sensory weighting into account as it influenced the operator's performance.

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A

DEFINITIONS OF TRUST

Various definitions of trust from several articles are collected and illustrated in Table A.1. The used colours -magenta, blue and red- indicate the similar aspects repeated over multiple definitions.

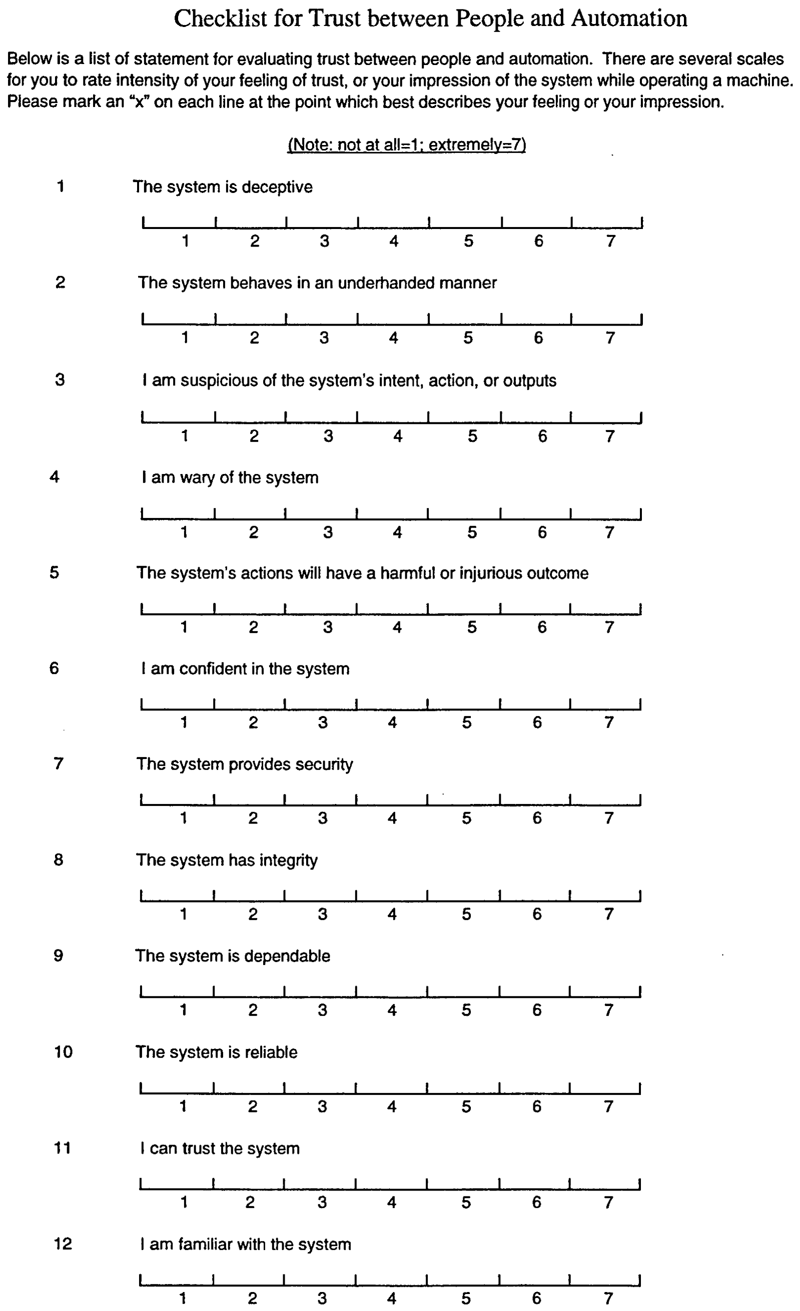
Table A.1: Quotes from various articles giving their definition of trust. Magenta showed the emotional aspects, blue the interacting agents and red the action that needs to be performed.

Author	Quote
Mayer et al. [21]	“the willingness of a party to be vulnerable to the outcomes of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party.”
Moray and Inagaki [23]	“… an attitude which includes the belief that the collaborator will perform as expected, and can, within the limits of its designers’ intentions, be relied on to achieve the design goals”
Madsen and Gregor [20]	…the extent to which a user is confident in, and willing to act on the basis of the recommendations, actions, and decisions of an artificially intelligent agent”
Hancock and Schaeffer [11]	"as the reliance by an agent that actions prejudicial to their well-being will not be undertaken by influential others."
Lee and See [18]	"the attitude that an agent will help achieve an individual’s goals in a situation characterized by uncertainty and vulnerability"

B

TRUST SURVEY

The survey used for measuring trust was created by Jian et al. [16]. The survey was composed by a United States Air Force Research Laboratory in 1998 and published 2000. The study analysed over 138 words concerning trust and distrust. The words were related to general trust, trust between humans, and trust between automation and humans. It was concluded that trust and distrust are opposites and can, therefore, be linearly compared. Furthermore, it was founded that people do not interpret general trust, trust between humans, and human-machine trust differently; though people find it harder to relate the concept of trust to machines compared to humans. Finally Jian et al. [16] created a survey, illustrated in Figure B.1 on empirical data to measure trust between humans and automation. As no significant difference was found between the trust relations the survey is also applicable in measuring trust between human and shared control.



Checklist for Trust between People and Automation

Below is a list of statement for evaluating trust between people and automation. There are several scales for you to rate intensity of your feeling of trust, or your impression of the system while operating a machine. Please mark an "x" on each line at the point which best describes your feeling or your impression.

(Note: not at all=1; extremely=7)

1 The system is deceptive

1 2 3 4 5 6 7

2 The system behaves in an underhanded manner

1 2 3 4 5 6 7

3 I am suspicious of the system's intent, action, or outputs

1 2 3 4 5 6 7

4 I am wary of the system

1 2 3 4 5 6 7

5 The system's actions will have a harmful or injurious outcome

1 2 3 4 5 6 7

6 I am confident in the system

1 2 3 4 5 6 7

7 The system provides security

1 2 3 4 5 6 7

8 The system has integrity

1 2 3 4 5 6 7

9 The system is dependable

1 2 3 4 5 6 7

10 The system is reliable

1 2 3 4 5 6 7

11 I can trust the system

1 2 3 4 5 6 7

12 I am familiar with the system

1 2 3 4 5 6 7

Figure B.1: Survey on trust between human and automation, created by Jian et al. [16]

C

GLOSSARY FOR TRUST SURVEY

All definitions are from the Oxford Dictionary [2]. Participants are supplied with the list when taking the trust survey.

1. **Deceptive:** “Giving an appearance or impression different from the true one; misleading.”

2. **Underhand:** “Acting or done in a secret or dishonest way.”

3. **Suspicious:** “Having or showing a cautious distrust of someone or something.”

4. **Wary:** “Feeling or showing caution about possible dangers or problems.”

5. **Harmful:** “Causing or likely to cause harm.” Harm: “physical injury, especially that which is deliberately inflicted.”

6. **Confident:** "Feeling or showing confidence in oneself or one’s abilities or qualities. Confidence: “The feeling or belief that one can have faith in or rely on someone or something.”

7. **Security:** “The state of being free from danger or threat.”

8. **Integrity:** “The quality of being honest and having strong moral principles.”

9. **Dependable:** “ Trustworthy and reliable.”

10. **Reliable:** “ Consistently good in quality or performance; able to be trusted.”

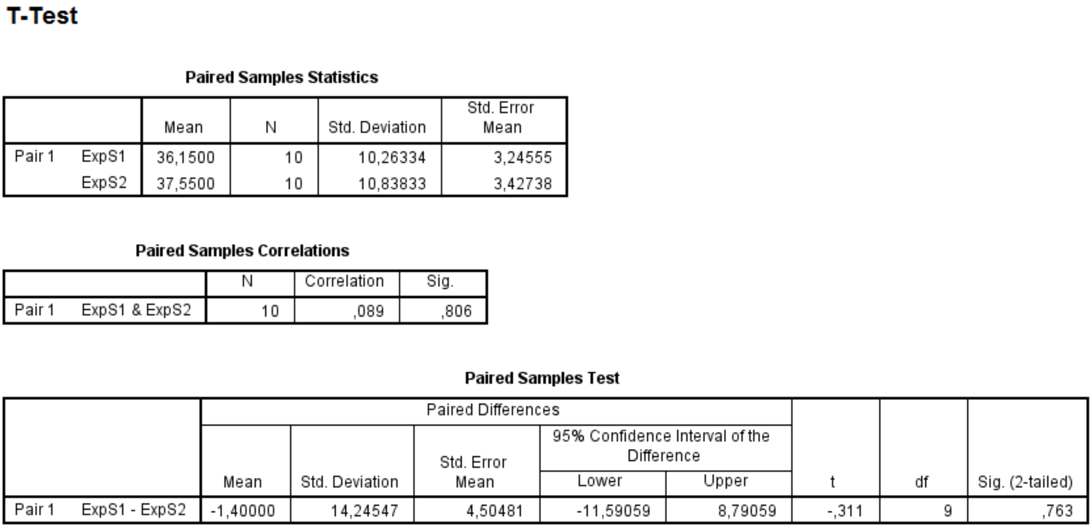
11. **Trust:** “Firm belief in the reliability, truth, or ability of someone or something.”

12. **Familiar:** “Having a good knowledge of.”

D

RESULTS TRUST SURVEY

A paired sampled t-test on the scores of the trust survey indicated that no significant change in trust occurred between the two experimental sessions.



T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ExpS1	36,1500	10	10,26334	3,24555
	ExpS2	37,5500	10	10,83833	3,42738

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ExpS1 & ExpS2	10	,089	,806

Paired Samples Test

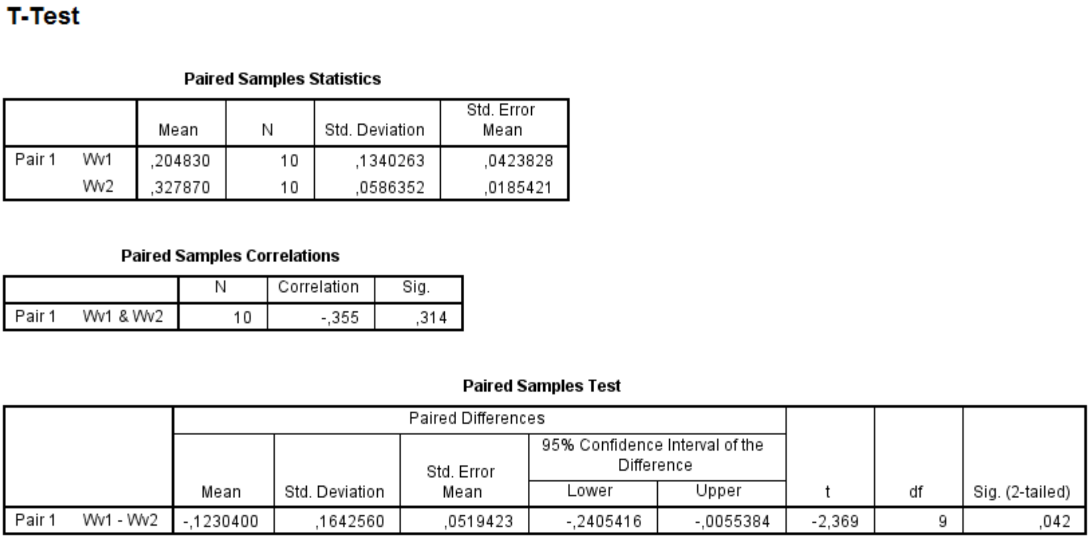
		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	ExpS1 - ExpS2	-1,40000	14,24547	4,50481	-11,59059	8,79059	-,311	9	,763

Figure D.1: Descriptive statistics of the sampled paired t-test for a change in trust. No significant result

E

Results sensory reweighting

A paired sampled t-test on the visual weight for experimental session one and two. A significant change of 0.042 was found.



T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Wv1	,204830	10	,1340263	,0423828
	Wv2	,327870	10	,0586352	,0185421

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Wv1 & Wv2	10	-,355	,314

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Wv1 - Wv2	-,1230400	,1642560	,0519423	-,2405416	-,0055384	-2,369	9	,042

Figure E.1: Descriptive statistics for sensory weight. Significant result.