Ambivalence in Attitudes towards Robots

Cumulative Dissertation

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by

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Contents

List of Manuscripts

This dissertation is based upon the following manuscripts:

I. Stapels, J. G., & Eyssel, F. (2021). Let's not be indifferent about robots: Neutral ratings on bipolar measures mask ambivalence in attitudes towards robots. *PloS ONE*, *16*(1), e0244697. https://doi.org/10.1371/journal.pone.0244697

II. Stapels, J. G., & Eyssel, F. (2021). Robocalypse? Yes, please! The role of robot autonomy in the development of ambivalent attitudes towards robots. *International Journal of Social Robotics*. https://doi.org/10.1007/s12369-021-00817-2

III. Stapels, J. G., & Eyssel, F. (Submitted for publication in *PloS ONE*). Torn between love and hate: Mouse tracking ambivalent attitudes towards robots.

Manuscripts I and II are available online open access. Manuscript III is appended at the end of this synopsis.

Summary

Nothing in life is to be feared, it is only to be understood.

Now is the time to understand more, so that we may fear less.

- Marie Curie

The current work investigated the under-researched topic of ambivalent attitudes towards robots from an experimental social psychological perspective. While ambivalence has been a research topic for almost a hundred years, it is often overlooked in the context of attitude research. When an attitude towards an attitude object is not clearly positive or negative, it is often interpreted as neutral. Depending upon the measurement method, ambivalent attitude objects may appear neutral, despite differing in terms of their positive and negative evaluations, their perceived subjective conflict, and the affective, behavioral and cognitive indicators of such conflict. In this work, we apply a theoretical framework, the ABC of Ambivalence (van Harreveld et al., 2015), to the domain of attitudes towards robots and thereby test the external validity of the model as well as enhancing our understanding of attitudes towards robots. In three manuscripts relating to five experiments and data from over 600 participants in total we demonstrated firstly, that attitudes towards robots are highly ambivalent. Secondly, we investigated the evaluation contents and dispositional differences influencing ambivalence towards robots in a mixed methods design. Thirdly, using implicit and explicit measures, we examined the behavioral, and cognitive indicators of ambivalence in attitudes towards robots, providing an updated ABC of Ambivalence, the AB of Robot-related Ambivalence. While self-reported attitudes were consistently highly ambivalent across experiments, the behavioral indicators of such ambivalence seemed to depend upon the type of robot. Further, the current research highlighted boundaries concerning the cognitive indicators of ambivalence, which could not be replicated in the domain of social robotics. Further research is required to investigate the specific cognitive and behavioral indicators of ambivalence. The current work demonstrates a novel interpretation of seemingly "neutral" attitudes towards robots, encouraging researchers to reinterpret and possibly replicate robot-related attitude research with the proposed methodology considering attitudinal ambivalence.

Ambivalence in Attitudes towards Robots

Nun lehrt uns die klinische Beobachtung,
daß der Haß nicht nur der unerwartet regelmäßige
Begleiter der Liebe ist (Ambivalenz) [...], sondern auch,
daß Haß sich unter mancherlei Verhältnissen
in Liebe und Liebe in Haß verwandelt.
- Sigmund Freud, Das Ich und das Es

What does Sigmund Freud have to do with attitudes towards robots? Both are connected to the phenomenon of ambivalence. The first scientist to coin the word "ambivalence" was the psychiatrist Eugen Bleuler, who described ambivalence as the phenomenon of holding positive and negative thoughts and feelings at the same time. He proposed that healthy individuals were able to extract the essence of the conflict and resolve their ambivalence, while to accept both sides as equally true was supposedly a symptom of schizophrenia (Bleuler, 1911). Sigmund Freud then integrated ambivalence into many of his theories from the 1910s and 1920s, which were based on case analyses of his patients. For example, Freud analyzed the ambivalence between love and hate concerning close people, or the ambivalence about death with a conflict concerning the honoring of ancestors and a fear of ghosts (Freud, 1913, as cited in Freud, 1989a). Freud viewed ambivalence as a normal psychological phenomenon, which would become clinically relevant in excessive amounts (Freud, 1923, as cited in Freud, 1989b). Since then however, scientists have tended to refrain from these types of interpretations regarding subconscious inner conflicts and instead have focused on observable variables (cf. Skinner, 1965; Watson, 1913), later additionally focussing on self-report and observation of cognition (cf. Bandura & Walters, 1977; Priester & Petty, 1996; Thompson et al., 1995). Ambivalence still fascinates researchers as it did one hundred years ago, though today it is primarily investigated as a characteristic of attitudes rather than a clinically relevant phenomenon (for an overview see Schneider & Schwarz, 2017).

Ambivalence in Social Psychological Research

Attitudes are defined as all evaluations regarding one object of thought (Bohner & Wänke, 2002) and prepare and guide behavior (Ajzen & Fishbein, 1977; Allport, 1935). Attitudes can be measured directly via self-report or indirectly via implicit measures (De Houwer, 2006) and they can be positive, negative, neutral, or ambivalent. Ambivalent attitudes are defined as consisting of positive and negative evaluations which are simultaneously accessible (K. J. Kaplan, 1972). For the longest time, ambivalence research has relied largely upon self-reports. However, self-report measures are prone to certain shortcomings which have been addressed by researchers for several decades.

Kalman J. Kaplan (1972) criticized the measurement of attitudes on semantic differentials, for example from positive to negative. The issue identified was that attitudes can be positive and negative *at the same time*. Since positive and negative attitude components are not reciprocal, they should not be measured on one bipolar semantic differential item, but rather be measured separately. Megan Thompson and colleagues (1995) contributed to the improved measurement of ambivalent attitudes through comparing several formulae of ambivalence integrating the positive and negative attitude components in terms of similarity and intensity. Based on empirical reasons (e.g., high internal consistency, predictive power), the authors recommended the "Griffin" formulation of ambivalence. The formulation reads: $(P+N)/2 - |P - N|$ with P being the positive evaluation and N being the negative evaluation. Accordingly, low values concerning both sides of the evaluations *or* a low value on one side and a high value on the other side result in a low value of ambivalence, while high values on both sides result in a high value of ambivalence. In this way, the objective existence of opposing evaluations can be quantified (Thompson et al., 1995).

The objective existence of opposing evaluations is not always equal to experienced conflict, however. Therefore, Joseph R. Priester and Richard E. Petty (1996) distinguish *objective ambivalence*, the objective existence of opposing evaluations, from *subjective ambivalence*, the experienced conflict and a feeling of being "torn" between the positive and negative evaluations.

Especially when both sides of evaluations are simultaneously accessible, they lead to subjective ambivalence. The authors proposed measuring subjective ambivalence in addition to objective ambivalence by instructing participants to rate their experience concerning an attitude object from 0 ("feel no conflict at all, feel no indecision at all, completely one-sided"; p. 437) to 10 ("feel maximum conflict, feel maximum indecision, completely mixed reactions"; p. 437). Since subjective and objective ambivalence measure different aspects of an ambivalent attitude, they do not always correlate highly (Armitage & Arden, 2007), but subjective ambivalence is a function of conflicting evaluations (objective ambivalence), speaking for a gradual threshold model of ambivalence rather than an abrupt threshold (Priester & Petty, 1996).

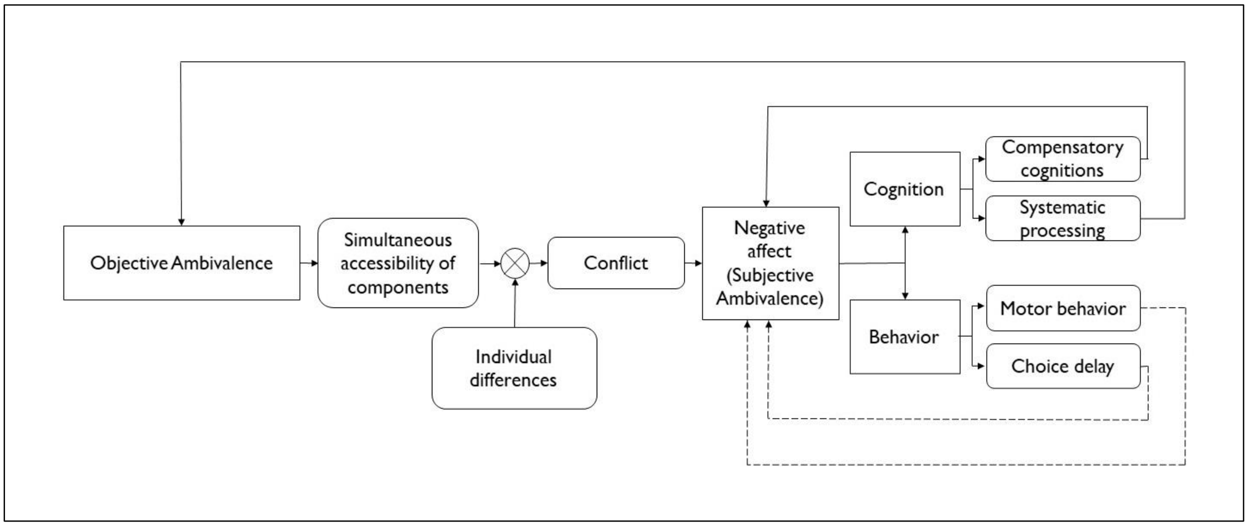
Ambivalence has since been investigated within various domains, e.g., regarding food choices (Gillebaart et al., 2016), online transactions (Moody et al., 2017), artificial intelligence (Maier et al., 2019) and self-driving cars (Liu, 2020). Though further, with the help of ambivalence research, stimuli which seemed to have been neutral could correctly be identified as ambivalent, e.g. supposedly neutral stimuli from the International Affective Pictures System (Schneider et al., 2016). The current research aims to extend ambivalence research to the domain of robotics, where ambivalence may consist of a different composition of "love" and "hate" than Sigmund Freund might have had in mind.

The ABC of Ambivalence

The distinction between neutrality and ambivalence is salient, since ambivalence carries different affective, behavioral, and cognitive consequences to neutrality. Extending the tripartite model of attitudes, Frenk van Harreveld and colleagues (2015) developed the ABC of Ambivalence, which served to integrate ambivalence research and proposed causal relationships between the affective, behavioral, and cognitive indicators of ambivalence (see **Figure 1**).

Figure 1

The ABC of Ambivalence. Reprinted from: van Harreveld, F., Nohlen, H. U., & Schneider, I. K. (2015). The ABC of Ambivalence: affective, behavioral, and cognitive consequences of attitudinal conflict. *Advances in Experimental Social Psychology*, *52*, 309, Copyright (2021), with permission from Elsevier.



As the model shows, objective ambivalence (the objective existence of opposing evaluations) leads to conflict when these evaluations are accessible simultaneously. Further, individual differences influence the experienced conflict arising from opposing evaluations: For example, a higher need for cognition and previous experience with the attitude object leads to less ambivalence (Thompson et al., 1995). Moreover, self-control leads to a quicker resolution of attitudinal conflict in behavioral measures (Schneider & Mattes, 2019). There may be several further factors, depending upon the attitude object, which cause individual differences in terms of the experience and resolution of ambivalence.

In contrast to neutrality or univalence, people who hold ambivalent attitudes experience higher inner conflict and arousal on the affective level and report feeling “torn” between the two sides of the attitude (Schneider et al., 2016). This struggle is called subjective ambivalence. Subjective ambivalence has several subsequent behavioral and cognitive indicators. On the behavioral level, ambivalent individuals delay decisions in the short term during decision tasks but also in the long term by postponing practical decisions concerning ambivalent attitude objects in the laboratory as well as in real-life situations (see choice delay). Concerning the motor behavior of participants, motor deviations can for example be measured via tracking mouse movements, where participants may even shift bodily from side to side when confronted with ambivalent stimuli measured using mouse tracking and a Wii balance board (a device which measures the posture and movement of participants when it is stood upon (Schneider et al., 2013)). On a cognitive level, ambivalence leads to differences in systematic information processing, e.g., the seeking of further information about the ambivalent attitude object, to compensatory cognitions, or to less susceptibility to bias (DeMarree et al., 2014). These cognitive and behavioral strategies can be interpreted as a means towards attenuating the aversive state of ambivalence. While self-reported ambivalence has been investigated in a broad array of studies, empirical evidence for the behavioral and cognitive implications proposed in the model is rather sparse.

The premise of the current work was that attitudes towards robots might also be ambivalent, and that such ambivalence may have been overlooked in social robotics research, as it has been overlooked in social psychological attitude research due to methodological shortcomings. We examined the applicability of the ABC of Ambivalence to the domain of robots, which may benefit both social robotics research through gaining further understanding of attitudes towards robots and ambivalence research through gathering further evidence concerning the proposed behavioral and cognitive implications of ambivalence. In order to do so, I first provide an overview of the current state of the literature concerning attitudes towards robots.

Attitudes towards Robots

Previous research has oftentimes described attitudes towards robots as neutral (Bernotat & Eyssel, 2018; Naneva, Gou, et al., 2020; Reich-Stiebert & Eyssel, 2015). Such works have provided valuable contributions to attitude literature, for example, concerning cultural differences in attitudes towards robots (Bernotat & Eyssel, 2018), or the need for cognition and technology commitment as important dispositional differences regarding attitudes towards social education robots (Reich-Stiebert & Eyssel, 2015). Even in a meta-analytic review on attitudes towards robots, Stanislava Naneva and colleagues have declared that attitudes towards robots would in sum be neutral to slightly positive, as measured for the most part via bipolar scales (Naneva et al., 2020). However, in light of ambivalence research we must reevaluate the interpretation of evaluations as neutral (for a detailed overview on this topic see Manuscript I).

Widely used measures of attitudes towards robots include the Negative Attitudes towards Robots Scale (NARS; Syrdal et al., 2009), Robot Anxiety Scale (RAS; Nomura et al., 2008) and Godspeed Questionnaire (Bartneck et al., 2009), which assess attitudes towards robots on bipolar items. In the current work, we argue that these bipolar measures do not capture ambivalence and attitudinal conflict, and also cannot distinguish between neutral and ambivalent (cf. Godspeed Questionnaire) or negative and ambivalent (cf. NARS) attitudes. This said, why do we need special instruments to measure attitudes towards robots?

Robot-characteristics as Determinants of Attitudes Towards Robots

Robots have certain characteristics that make them a special attitude object and that distinguish them from other attitude objects. A recent meta-analysis has suggested that robot-characteristics may even be more important developing trust in robot compared to human-related or contextual factors (Hancock et al., 2020). One example of a robot characteristic is the robot's proxemics behavior, as appropriate robot proxemics behavior positively influences robot evaluation (Petrak et al., 2021).

As robotic technologies developed in recent years, robots have become ever more autonomous. This autonomy gives robots the opportunity to sense their environment, plan their behavior and act upon those plans (Beer et al., 2014). Repeatedly, robots have been declared our future companions, blurring the line between object and social agent (cf. Krämer et al., 2012). This omission of a strict separation of objects vs. humans might seem frightening, both realistically and idealistically (Ferrari et al., 2016; Złotowski et al., 2017). That is, people might feel threatened realistically, for fear of being attacked by a robot or by their home robot being hacked. Furthermore, they might feel threatened idealistically by being uncomfortable with humanlike beings which threaten humanity's leading position on earth. This autonomy and novelty might go hand in hand with ambivalence, since hopes and fears associated with robots increase with increasing autonomy. As a consequence of an increase in both positive and negative evaluations, it can be expected that attitudinal ambivalence will be high for highly autonomous robots.

Robot autonomy differs between types of robots. For example, an industrial robot is less autonomous than a social robot, since the industrial robot only performs programmed tasks and cannot sense its environment and plan behavior, in contrast to the social robot. In order to be able to generalize the notion of ambivalence in attitudes towards robots, the current research encompasses a broad range of robot stimuli, from the simple word "robot" to various robot-related words and pictures, including a specific description of a situation with a newly developed social robot. However, not only *robot* characteristics influence attitudes towards robots, but also *user* characteristics.

User-characteristics as Determinants of Attitudes Towards Robots

Not every person reacts in the same way to new technologies. Some people might be particularly skeptical towards technologies entering their homes, while others may crave new technologies that might give them opportunities for connecting with others.

Technology Commitment. People collect different experiences with technology throughout their lives and differ in their readiness to engage with novel technologies (Neyer et al., 2012). People high in technology commitment may hold more positive attitudes towards robots and be more acceptant of them in their everyday lives (Bernotat & Eyssel, 2017; Reich & Eyssel, 2013). One possible mechanism here is that people high in technology commitment potentially experience less subjective ambivalence and negative affect from their opposing evaluations since they could be better able to integrate these evaluations with previous knowledge.

Chronic Loneliness. Loneliness is a highly aversive state and causes people to seek out ways to engage with others (Russell et al., 1980). For example, loneliness changes the perception of humanlike agents, such as social robots. Specifically, lonely people tend to attribute mind to robots and see them as more humanlike (anthropomorphism; Eyssel & Reich, 2013). Robots can even help decrease loneliness in elderly people in care homes (Robinson et al., 2013). Therefore, loneliness might diminish attitudinal conflict by increasing the hopes for a rewarding interaction with robots while disregarding disadvantages. In contrast, Robots are often declared as both assets and dangers regarding lonely people, which might result in higher attitudinal ambivalence. Thus, the connection between loneliness and ambivalence towards robots is yet to be investigated.

Tendency to Anthropomorphize and the "Big Five" factors of personality. On a similar note, the tendency to attribute human-like characteristics to non-human entities is called anthropomorphism and is determined by knowledge about an entity, motivation to explain its behavior, and motivation to engage socially (Epley et al., 2007). However, it is unclear what the consequences of such anthropomorphism are. It is possible that people see anthropomorph robots as more positive to a certain extent due to their human likeness. At some point however, anthropomorph robots might be also perceived as more negative in certain cases, as the *Uncanny Valley* suggests (Mori, 1970). The Uncanny Valley describes the phenomenon that robots are evaluated more favorably as they become more humanlike, while evaluations show a drastic decrease as robots become almost humanlike, but not perfectly so (e.g., in the case of android robots). Such humanlike robots seem especially eerie and terrifying.

Moreover, the Big Five factors of personality, namely neuroticism, extraversion, openness, agreeableness, and conscientiousness influence how we perceive and interact with our surroundings (John et al., 1991), an thus, might also influence the perception of robots. For example, extraversion, one of the Big Five factors of personality, positively influences the tendency to anthropomorphize robots (A. D. Kaplan et al., 2019). Therefore, anthropomorphism might be connected to the experience of ambivalence. The specific role of anthropomorphism and personality characteristics in attitudinal conflict are yet to be investigated.

Self-Control. Self-control is a general tendency to put back short-term goals in favor of long-term goals (Tangney et al., 2004). People high in self-control are better adjusted and more successful than people low in self-control. This tendency even translates to the decision-making process. Participants high in self-control resolved ambivalence more quickly in evaluation tasks (Schneider et al., 2019). If this effect is generalizable, people high in self-control might also resolve robot-related conflict more quickly.

In order to come to a better understanding of the role of dispositional differences in the experience and resolution of ambivalence in attitudes towards robots, the aforementioned variables have been integrated into the current research within Manuscripts II and III.

The Present Research

Never trust anything that can think for itself
if you can't see where it keeps its brain.
- J.K. Rowling, Harry Potter and the Chamber of Secrets

The goal of the present research was threefold: First, we investigated empirically whether attitudes towards robots would in fact be ambivalent. Second, we explored determinants influencing ambivalence. Third, we investigated the affective, behavioral, and cognitive indicators of ambivalence in attitudes towards robots, in order to provide an updated ABC of Ambivalence applied to social robotics, as well as identify potential boundaries of its generalizability.

Manuscript I: Let's not be indifferent about robots: Neutral ratings on bipolar measures mask ambivalence in attitudes towards robots

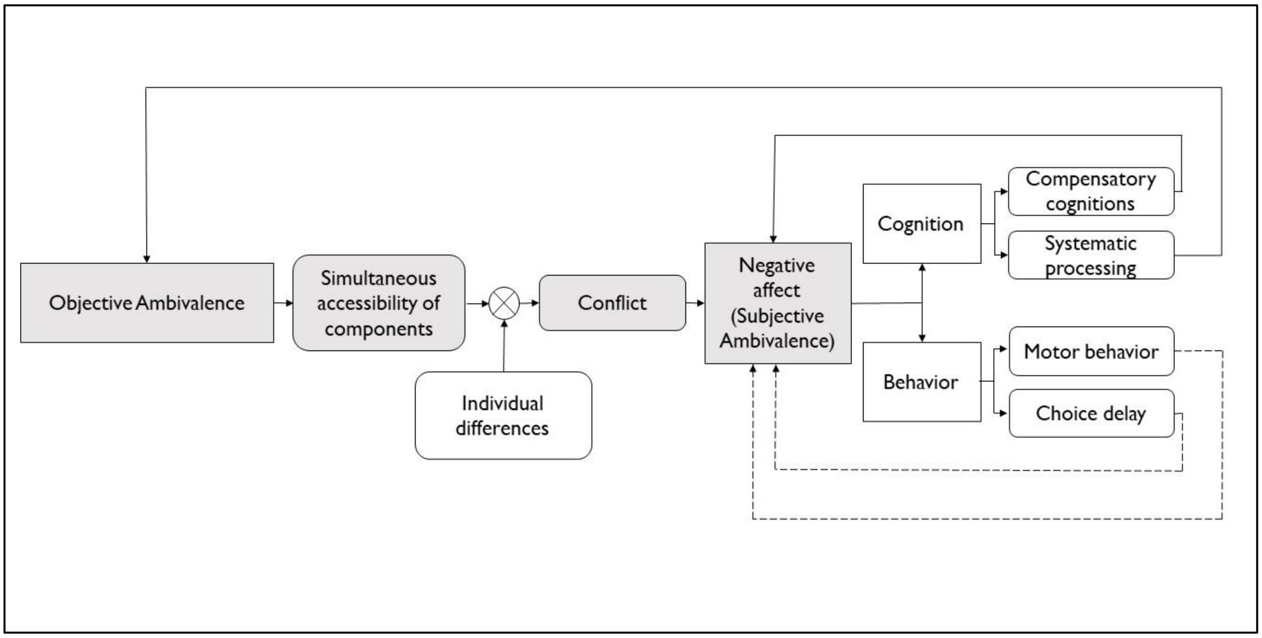
In order to investigate empirically whether attitudes towards robots would in fact be ambivalent, we conducted the one-factorial within-participants experiment described in Manuscript I. Previous research on attitudes towards robots has described them as neutral (e.g., Bernotat & Eyssel, 2018). However, previous social psychological research has shown empirically that attitudes might appear neutral depending upon the measure, while they are in fact ambivalent. Comparing the evaluation of a robot stimulus (i.e., the word "robot") with a stimulus pretested as neutral (i.e., the word "stapler"), we hypothesized that participants' ratings would not differ in valence measured using one bipolar item, but would indicate higher subjective ambivalence, objective ambivalence, and arousal towards the robot stimulus compared to the neutral stimulus. That is, participants would feel ambivalent (i.e., both positively and negatively at the same time) about robots which might appear as a neutral evaluation on a bipolar valence scale. Data analyzed in Manuscript I were provided in the supplementary materials with the paper.

Results indicated that this was indeed the case: equivalence testing showed no difference in a bipolar valence item between robots and staplers. In contrast, objective ambivalence, subjective ambivalence, and arousal were higher towards robots than towards the truly neutral stimulus. Participants showed highly positive *and* highly negative evaluations towards robots, but weakly positive and weakly negative evaluations towards staplers. Participants indicated higher feelings and thoughts of conflict towards robots than towards staplers. In addition to demonstrating the ambivalent nature of robots, we showed the affective consequence: evaluating the robot stimulus led to higher arousal than evaluating the stapler stimulus, even on such an abstract stimulus level. Large effect sizes underlined the practical significance of the findings. This work contributes to ambivalence literature by extending the theoretical framework to the domain of robots and by showing that robots are indeed ambivalent stimuli, while currently used attitude measures must also be altered to account for both sides of the evaluation as well as the experience of conflict. Including the notion of ambivalence in robot research carries potential for improving our understanding of attitudes towards robots as well as improving predictions of behavior from those attitudes.

When interpreting the results in light of the ABC model of ambivalence, the positive and negative evaluations which constitute overall objective ambivalence were made simultaneously accessible through ratings of positivity and negativity (see **Figure 2**). This leads to conflict and negative affect.

Figure 2

The ABC of Ambivalence (van Harreveld et al., 2015). Highlighted components were tested in Manuscript I.



To sum up, attitudes towards the word "robot" are ambivalent. Whether the results could be transferred to other robot-related stimuli, the causes of robot-related ambivalence as well as the dispositional differences influencing ambivalent attitudes remained unclear. These were investigated in Manuscript II.

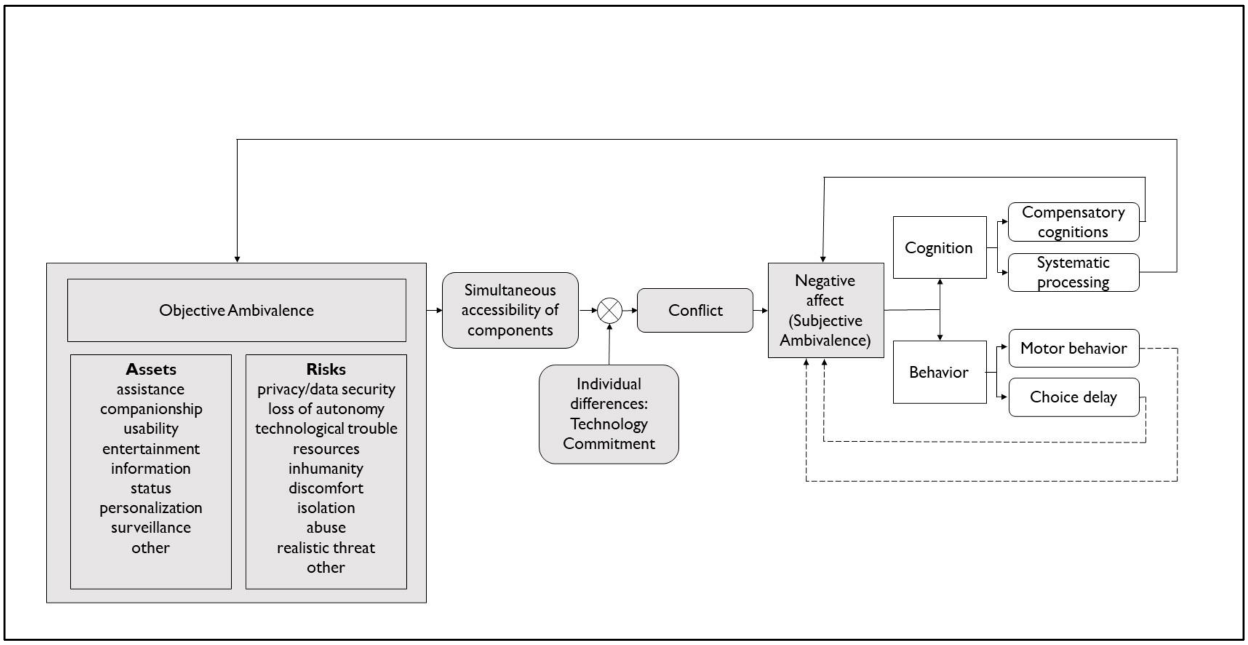
Manuscript II: Robocalypse? Yes, please! The role of autonomy in the development of ambivalent attitudes towards robots

In addition to demonstrating ambivalence in attitudes towards robots on the quantitative level, we investigated robot autonomy as a potential source of ambivalence, as well as evaluation contents and dispositional differences in the experience of ambivalence towards robots, within a mixed methods vignette experiment. Here, we manipulated robot autonomy (low vs. high) and assessed objective and subjective ambivalence using quantitative and qualitative measures. Concerning the dispositional variables, we considered only technology commitment and chronic loneliness in the current experiment. We chose technology commitment since it had previously been shown to influence attitudes towards robots (Reich & Eyssel, 2013) and we investigated the specific mechanisms of the influence of technology commitment on attitudes towards robots. Moreover, we explored the influence of chronic loneliness on attitudes towards robots. We hypothesized that both positive and negative evaluations would increase with higher robot autonomy, resulting in higher ambivalence. Data analyzed in Manuscript II can be accessed at PUB – Publications at Bielefeld University, a service of the university's library (https://pub.uni-bielefeld.de/record/2956845).

Results again implied that attitudes were ambivalent overall. While autonomy did not impact objective ambivalence, subjective ambivalence was higher in the high autonomy condition. However, the difference became nonsignificant when controlling for technology commitment. Correlational analyses showed that people high in technology commitment might experience less subjective ambivalence towards robots compared with people low in technology commitment. Consequently, one possible mechanism might be that autonomy influences ambivalence only for people low in technology commitment, as these people may feel more quickly threatened by novel technologies due to their lack of experience. Regarding exploratory analyses, loneliness did not correlate with ambivalence. However, further exploratory results regarding behavioral intentions indicated that people high in subjective ambivalence might be less likely to be interested in having a robot at home compared to people low in subjective ambivalence, while there was no significant difference concerning their interest in meeting a robot in a future experiment. Qualitative results indicated that the experienced conflict might arise from assets (i.e., assistance, companionship, usability, entertainment, information, status, personalization, surveillance, other) and risks (i.e., privacy/data security, loss of autonomy, technological trouble, resources, inhumanity, discomfort, isolation, abuse, realistic threat, other) associated with having a social robot at home (see **Figure 3**). These assets and risks can be utilized to improve future social robots and might also inspire researchers in social psychological research to extend quantitative measures by qualitative measures to gain detailed insight into the evaluation contents influencing attitudes.

Figure 3

The ABC of Ambivalence (van Harreveld et al., 2015), extended through qualitative data on evaluation contents and the trait variable of technology commitment. Highlighted components were tested in Manuscript II.



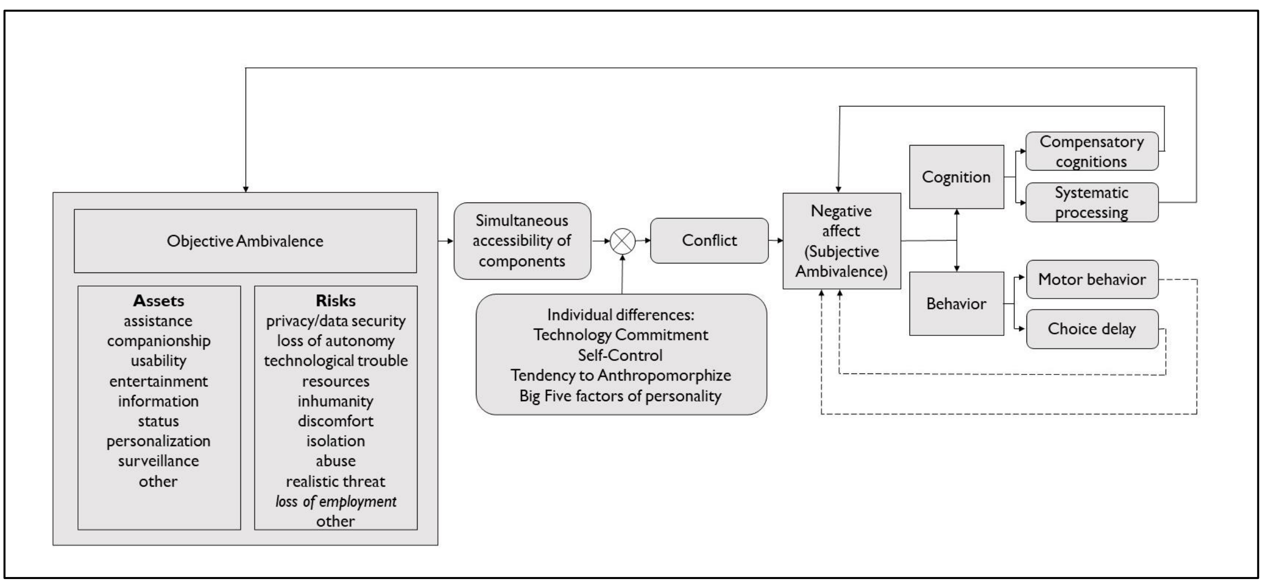
This demonstrates that hopes or fears towards robots can never be analyzed separately. Both go hand in hand: for example, a fear of social isolation can only be experienced when a robot is seen as autonomous enough to engage in a social relationship having the potential to isolate the user from other people. Alternatively, a fear of privacy or security violations is only relevant when a robot is autonomous enough to engage in planned actions and collect data relevant to privacy. Taken together, the results demonstrate the notion of ambivalent attitudes towards autonomous robots, highlighting the importance of dispositional differences. Furthermore, insights from qualitative data can help further social robotics research and user-centered robot development, highlighting the relevance of multi-method approaches concerning ambivalent attitudes in general.

Manuscript III: Torn between love and hate: Mouse tracking ambivalent attitudes towards robots.

After establishing the notion of ambivalence in attitudes towards robots and exploring possible causes, we investigated the cognitive and behavioral indicators of ambivalence. We extended our results from mere self-report to response time based measures. We did so in four mouse tracking experiments using various stimuli. Tracking mouse movements provides the opportunity not only to analyze response times during an evaluation task, but additionally to track the path of a mouse during the evaluation, providing insights into the magnitude and resolution of experienced conflict (cf. Freeman & Ambady, 2010; Schneider et al., 2015). During a dichotomous evaluation task requiring participants to indicate their evaluation of a stimulus with a computer mouse as "positive" or "negative", the highest deviation of the participants' mouse path from the ideal, direct path is measured as an indicator of ambivalence (Maximum Deviation; MD). This deviation towards the non-chosen option reflects the "motor behavior", as depicted in the ABC of Ambivalence (see **Figure 4**).

Figure 4

The ABC of Ambivalence (van Harreveld et al., 2015), extended through dispositional variables. All components were tested in Manuscript III.



Secondly, overall response time is recorded, constituting “choice delay”. Further, in Experiments 2 to 4 we assessed contact intentions towards robots as another measure of behavioral intentions which might be influenced by ambivalent attitudes. Concerning the cognitive indicators of ambivalence, we assessed information search concerning robots in Experiments 2 to 4, as an operationalization of systematic processing, as in DeMarree et al. (2015). We further explored compensatory cognitions, through analyzing qualitative responses concerning ambivalence towards robots from Experiment 1.

In the current experiments in Manuscript III, we measured objective ambivalence, subjective ambivalence, MD, response times, contact intentions towards robots, and information search towards robots. As stimuli we utilized various robot category words (service robot, industrial robot, medical robot, exploration robot, social robot) and robot function words (social function, personalizability, mobility, video function, voice control) in Experiment 1, general robot-related words (android, humanoid, robot, robotics, robotic, robot-like) in Experiment 2, machine-like robot pictures and humanoid robot-pictures in Experiment 3, and various social robot pictures in Experiment 4, and univalent words and pictures, respectively. Participants were asked to evaluate all stimuli as “positive” or “negative” and mouse trajectories were recorded. We chose univalent stimuli as a comparison since they evoke clear positive or negative responses on the affective, behavioral, and cognitive level, in contrast to ambivalent stimuli. Due to a technical error, MD and response times were not recorded in Experiment 4. We further measured contact intentions and information search in Experiments 2 to 4. Concerning dispositional variables, we assessed technology commitment in all experiments. Self-control and loneliness were assessed in Experiment 1, the Big Five factors of personality in Experiment 2, and tendency to anthropomorphize in Experiments 2 to 4. Data analyzed in Manuscript III were submitted with the paper and will be made openly available after peer review.

As predicted, subjective ambivalence and objective ambivalence were higher towards robot stimuli than for univalent stimuli. However, Maximum Deviation was higher only for robot function words, general robot words, and machine-like robot pictures, when compared to univalent stimuli. There was no significant difference between robot category words and humanoid robot pictures compared to univalent stimuli. This might indicate that the behavioral indicators, especially motor behavior, caused by attitudinal ambivalence towards robots, might be moderated by the type of robot being evaluated. Interestingly, response times were significantly higher towards all types of robot stimuli compared to univalent stimuli. Thus, choice delay as a behavioral indicator of ambivalent attitudes was observed consistently over all four experiments. Lastly, contact intentions, as a measure of behavioral intentions which might be influenced by ambivalent attitudes, did not correlate with ambivalence. This might indicate that despite its aversive nature, ambivalence does not necessarily prevent potential users from being interested in engaging with robots.

Contrary to our expectations, systematic processing as a cognitive indicator of ambivalent attitudes did not correlate significantly with ambivalence. Therefore, in the experiments in Manuscript III, we found no evidence of ambivalence causing more information search about the ambivalent attitude object. However, future research might employ differentiated methodology and investigate which information is requested rather than measuring the general interest in information about the attitude object. For example, researchers may offer participants information on advantages and disadvantages concerning robots and investigate, which and how much information is requested. It might be hypothesized that participants with highly ambivalent attitudes request more, but also one-sided information in order to diminish their attitudinal conflict. Further, concerning compensatory cognitions, we found indications in Experiment 1 using qualitative data that many participants tried to solve their attitudinal conflict by especially strong arguments, weighting one side of their argumentation as more important.

Concerning individual differences, we found no consistent significant correlations between ambivalence and technology commitment, self-control, anthropomorphism, and the Big Five factors of personality. While in Experiment 1 technology commitment correlated negatively with MD, this effect could not be observed in Experiments 2 and 3. It is possible that the influence of technology commitment is context-sensitive: just as in Manuscript 2, where technology commitment correlated negatively with subjective ambivalence, in Experiment 1 of Manuscript III the information on the robot was very concrete, introducing specific arguments for and against the use of robots. One explanation might be that a participant's high technology commitment might only buffer the adverse effects of ambivalence when the evaluations causing ambivalence are concrete. Such concrete evaluations may be easier to interpret with high technology trust and knowledge. Technology commitment might be less influential when evaluating overall robot categories on a general level. This corresponds to the Construal Level Theory (Trope & Liberman, 2010), which proposes low levels of abstraction as parallel with low levels of psychological distance. The concrete nature of evaluations might then cause a topic to be felt as closer in terms of psychological distance and more relevant, causing higher levels of ambivalence.

To extend the model to social robots, in Manuscript III we integrated all parts of the original ABC of Ambivalence. This way, using mouse tracking, we proposed a method for the implicit measurement of ambivalent attitudes towards robots which other researchers in the field may adapt. While it remained clear that attitudes towards robots are ambivalent and cause choice delay, behavioral and cognitive indicators require further investigation both in the domain of social robotics and ambivalence research overall.

General Discussion

"Curiouser and curioser!"
- Lewis Carroll, Alice's Adventures in Wonderland

In the present research, we investigated ambivalence towards robots on the affective, behavioral, and cognitive level. Firstly, in Manuscript I we showed that attitudes towards robots are ambivalent and that they evoke heightened arousal as an affective indicator of ambivalence. Here we demonstrated empirically that ambivalent attitudes towards robots have likely been mistaken for neutral attitudes within past robotics research and propose using measures which assess the positive and the negative sides of an attitude separately and account for attitudinal conflict. This might help future researchers interested in attitudes towards robots to assess attitudes towards robots in a more valid way, providing them with further methods derived from ambivalence research.

In Manuscript II we investigated evaluation contents and individual differences influencing ambivalent attitudes towards robots. We identified robot autonomy as a potential factor which increases both positive and negative evaluations, and hence ambivalence. However, the trait variable of technology commitment had an impact on the evaluations, overriding autonomy-induced differences in subjective ambivalence. Further, using qualitative data, we identified causes for ambivalence towards robots and thus, starting points for improving attitudes towards robots. This improvement might be achieved by integrating the robot-related assets and risks voiced by potential users into the design process, e.g., by designing a robot as helpful, social, and entertaining. Additionally, features which users fear could be diminished in the design process, or users could be informed about the actual extent of robot-related risks, since many fears are inspired by science fiction media. For example, researchers working with robots and robot developers might provide detailed information about data privacy and measures taken to ensure robot security. Concerning social functions, strategies for enhancing social contact with other humans might be developed, rather than conversation functions that bear the potential to isolate users from other humans. In this way positive evaluations might improve, and negative evaluations could be diminished, resulting in a reduction of ambivalent attitudes.

In Manuscript III, we investigated ambivalence on a behavioral level and examined potential cognitive indicators of ambivalent attitudes towards robots. While response times as a behavioral indicator of ambivalence were consistently higher towards robot-related stimuli compared to univalent stimuli, MD as an indicator of ambivalence in motor behavior was only higher concerning robot function words, general robot-related words, and machine-like robot pictures but not concerning robot category words and humanoid robot pictures. Nevertheless, self-reported objective and subjective ambivalence was significantly higher concerning all robot stimuli. This might indicate that deviations in motor behavior during robot-related decisions depend on the type of robot stimulus, while self-reported ambivalence does not. Future social psychological research may investigate whether this conditional correlation can also be found for stimuli unrelated to robots and examine the underlying psychological mechanisms. Concerning the cognitive indicators of ambivalence, first exploratory results suggested the emergence of compensatory cognitions, with participants potentially focusing on especially strong arguments to attenuate their attitudinal conflict. Further research may investigate this connection experimentally.

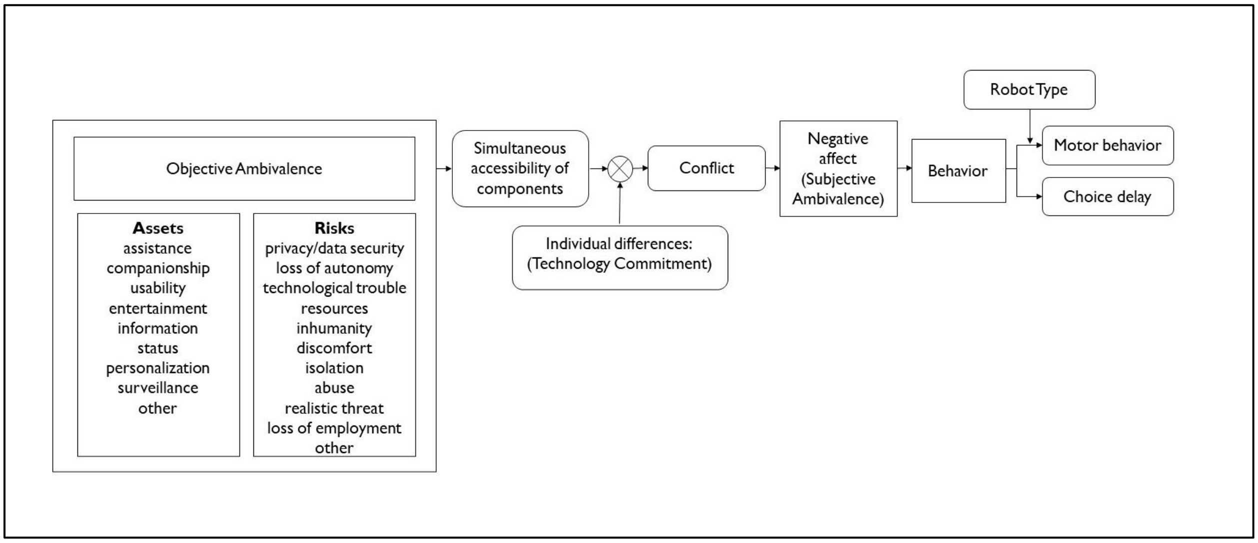
In general, we showed that the ABC of Ambivalence is applicable to the domain of social robots. However, the generalizability of behavioral and cognitive indicators of ambivalence might depend on the specific type of robot to be evaluated. Further, trait variables might influence ambivalence towards robots depending on the specificity of the presented information. Based on qualitative data, we gained further information on the causes of ambivalence in attitudes towards robots and the cognitive indicators, whilst introducing an approach to categorizing expected risks and assets concerning robots.

The AB of Robot-related Ambivalence

The findings from our repeated application of the ABC of Ambivalence were adapted to a figure of robot ambivalence (see **Figure 5**).

Figure 5

The adapted AB of Robot-related Ambivalence, based on research presented here.



Attitudes towards robots were highly ambivalent in Manuscripts I, II and III. Various assets and risks concerning robots lead to objective ambivalence, which causes subjective ambivalence and negative affect, partly depending on the technology commitment of users as shown in Manuscript II. However, a connection between technology commitment and ambivalence could only partly be replicated in Manuscript III. Ambivalence towards robots causes choice delay in robot evaluations and, depending on the robot type, a shift towards the non-chosen option in motor behavior as discussed in Manuscript III. Also in Manuscript III, we could not replicate the cognitive indicators of ambivalence derived from the literature. We have found exploratory indications of ambivalent users engaging in compensatory cognitions; however, this effect must still be tested experimentally in order to be integrated into the model. Further research might extend the AB of Robot-related Ambivalence by investigating the cognitive processes prompted by ambivalent attitudes towards robots.

Suggestions for the Measurement of Attitudes towards Robots

Based on the current work, suggestions for the measurement of ambivalent attitudes in self-report as well as on the behavioral and cognitive level are provided in the following. Firstly, concerning self-report, I suggest that researchers investigating attitudes towards robots assess positive and negative evaluations separately. For example, one might assess the valence of attitudes towards a robot stimulus using the following items (Thompson et al., 1995):

“How positive do you find [stimulus]?”

“How negative do you find [stimulus]?”

Here, [stimulus] can be substituted by a robot-related word, the robot’s name, or by any other reference to the respective stimulus. The answer constitutes of a Likert-scale ranging from 1 (not at all) to 7 (very). However, other Likert-scale sizes are also permissible. We used adaptations of these two items in all experiments of the current work. In addition to positivity and negativity, these items also provide the means to calculate a value of objective ambivalence, using the “Griffin” formula: $[(P + N)/2] - |P - N|$, with P corresponding to the positive evaluation and N corresponding to the negative evaluations of the respective attitude object (Thompson et al., 1995). Low results indicate low ambivalence (e.g., univalence or neutrality), while high values indicate high ambivalence. We provide the syntax for calculating objective ambivalence and further analyses for the software R in the supplementary materials of Manuscript I and for the software SPSS in the supplementary materials of Manuscript II. This measurement is a parsimonious way of assessing both valence and the existence of opposing evaluations in attitudes.

If researchers are additionally interested in participants’ evaluation contents, they might replicate the approaches from Manuscript II and Experiment 1 in Manuscript III and ask participants to list positive or negative thoughts or feelings associated with the respective stimuli. In Manuscript II we provided participants with ten numbered lines for positive evaluations and ten numbered lines for negative evaluations (DeMarree et al., 2014). We instructed participants to use one line per key point and informed them that they did not need to use all ten lines but could use as much space and time as needed. Participants listed up to 16 arguments so I assume that 20 lines in total will be sufficient for most research questions. If applicable, researchers may analyze the qualitative data by having two independent raters categorize answers into the assets and risks categories provided in the AB of Robot-related Ambivalence. Alternatively, the data may be analyzed "bottom-up" using the Grounded Theory Approach, which is explained in Manuscript II. From the number of arguments, a score of objective ambivalence may be calculated using the aforementioned "Griffin" formula. However, since the data does not contain information on the importance of each evaluation, this value is likely less accurate than using the two items above.

To additionally assess the perceived conflict arising from opposing evaluations, namely subjective ambivalence, researchers may use one item (Priester & Petty, 1996):

'To what degree do you experience conflicting thoughts and/or feelings?'

The answer is recorded on a Likert-Scale from 1 (no conflicting thoughts/feelings) to 7 (completely conflicting thoughts/feelings). Again, the scale length may be adapted according to the researchers needs. While in Manuscripts I and II we utilized a three-item measure tapping into subjective ambivalence, in the four experiments of Manuscript III we used the one-item measure to reduce the effort for participants who evaluated many items repeatedly (i.e., in the mouse tracking task and in self-report). Since we obtained comparable results, in terms of parsimony I suggest using the one item measure to assess subjective ambivalence.

In addition to self-report, ambivalence may be assessed on the behavioral level. Response times, which can serve as one indicator of ambivalence, for each item can be recorded with many widely used survey software options. Qualtrics, for example, provides the opportunity to record the time-stamps of the first and last click made on a page, which we utilized in Manuscript II. However, this method is not as accurate as using software specifically developed for recording response time data. Here, the *Mouse Tracker* software used in Experiment 1 of Manuscript III by (Freeman & Ambady, 2010) or the Qualtrics package used in Experiments 2 to 4 of Manuscript

III by (Mathur & Reichling, 2019) are user-friendly and validated options which may be used in future experiments on robot-related attitudes. In addition to response times, the softwares assess MD and many further variables, for example cursor speed. While the Qualtrics package provides the opportunity to collect data online and integrate it into a Qualtrics survey assessing self-report data and includes a template for programming as well as R code to analyze it, it still takes slightly more effort to analyze compared to the *Mouse Tracker* software. Regardless of the software, it is highly recommended to conduct research concerning response time data in the laboratory instead of online to avoid high data exclusions due to variations in hardware, internet connectivity problems, or not using a computer mouse as instructed, which is necessary in order to record mouse trajectories. Aside from having participants evaluate robot stimuli as “positive” or “negative” as in Manuscript III, it would also be possible to record mouse movements during decisions concerning behavioral intentions. For example, participants may be asked “Would you like to meet the robot?” or “Would you like further information regarding the robot?” with “Yes” and “No” as answer buttons in order to gain further insight into the decision making process concerning the influence of ambivalence on behavioral intentions towards robots. It should be noted that tracking mouse trajectories is only possible with stimuli involving only little text (e.g., one word), because the decision making process might already take place during reading longer questions.

Finally, regarding the cognitive indicators of ambivalence, no clear recommendation can be made based upon the current work, since we cannot determine whether the absence of the expected results in Manuscript III is caused by the absence of an effect or due to the measures used to assess cognitive indicators. Future research might adapt the methodology reported in Manuscript III or adapt further measures discussed in the ABC of Ambivalence (van Harreveld et al., 2015).

Strengths and Limitations

Many strengths of the current work are of a methodological nature: we conducted preregistered, mixed methods experiments with the use of multimodal stimuli, replicating aspects of the current work as well as methodology from previous works. To improve the transparency and replicability of the Manuscripts we provide data and syntax to other researchers and aimed to publish all manuscripts via open access. Moreover, we transferred a model from social psychology to social robotics and introduce the AB of Robot-related Ambivalence. Importantly, the ABC of Ambivalence was not proposed as a theoretical model but rather as an empirical overview of the state of ambivalence research. In the current work, we applied the model to the domain of attitudes towards robots and tested the generalizability and limitations of the model.

As a limiting factor to the current work, we did not conduct any direct human-robot interaction-based research. We focused on prospective attitudes towards robots, as they depict the current status of the robot in society. Moreover, laboratory-based studies with robots could not be conducted from March 2020 onwards due to the Covid-19 pandemic and we had to rely on online experiments for three of the four experiments in Manuscript III. Furthermore, we used mostly student samples, which is often the case in psychological research (Baxter et al., 2016). However, attitudes towards robots might be influenced by technology commitment, which is usually higher in student samples compared to more diverse samples concerning age and educational background. We expect general ambivalence as well as the concerns and hopes voiced in qualitative data to be similar in other demographic groups, though the individual relevance might differ. For example, while younger users might deem entertainment functions or social functions of a robot important, older users might appreciate aspects associated with usefulness in everyday life. The qualitative approach from Manuscript II might be conducted in different samples regarding age and level of education in order to gain further insight.

Future Research

Many ideas for furthering research on ambivalent attitudes towards robots have been suggested throughout the current work. Follow-up studies should replicate the current research in diverging samples and in real life human-robot interaction to extend the external validity of the current results. Further, various methods concerning cognitive indicators of ambivalence should be used to gain further insight into the resolution of attitudinal conflict towards robots. For example, one could further inquire on compensatory cognitions as a consequence of ambivalence which were indicated in the qualitative data in Manuscript III. To test whether participants with ambivalent attitudes towards robots actually concentrate on especially strong arguments in order to resolve ambivalence, future studies might have participants rate their own positive and negative evaluations in terms of strength and investigate whether overall subjective ambivalence correlates with the occurrence of strong arguments. To further test this effect experimentally, high or low levels of ambivalence might be induced using the assets and risks provided in the current work as an experimental manipulation. For example, text-based vignettes may be developed that include only positive *or* negative arguments (univalence), or positive *and* negative arguments (ambivalence). Said vignettes may also be replaced by a robot introducing itself with the same arguments. Based on the manipulation, one could have participants decide whether they would like to have such a robot integrated into their life and why. Again, argument strength could be rated by participants themselves and it could be determined whether especially strong arguments occur more often in the high-ambivalence condition.

Based upon the qualitative data, interventions might be designed to decrease fears and ameliorate the hopes towards robots, in order to attenuate the aversive state of ambivalence and potentially increase robot acceptance. One central aspect in users' negative evaluations of robots seems to be privacy concerns. To combine the two aspects of compensatory cognitions and privacy concerns, research investigating the influence of the possibility to choose a robot's privacy settings on self-reported ambivalence and compensatory cognitions is currently underway.

Conclusion

Attitudes towards robots are ambivalent, and this ambivalence leads to feelings of conflict, arousal, and behavioral indicators in the form of choice delay and, conditionally, motor behavior. Positive evaluations towards robots go hand in hand with negative evaluations towards robots, or, as Sigmund Freud would say, robot hate is the ubiquitous companion of robot love. Ambivalence should be measured in robot-focused attitude research, while the hopes and fears of potential users concerning robots may be integrated in robot development. For this purpose, we provide the AB of Robot-related Ambivalence, which may be reevaluated and extended by future research. Above and beyond, the current research demonstrated that further research is required on the internal and external validity of behavioral and cognitive indicators of ambivalent attitudes in general. Moreover, existing results concerning attitudes towards robots might be reinterpreted with the notion of ambivalence, and optimally be replicated with valid measurement tools that allow assessing ambivalence.

It might be that this suggestion evokes ambivalence in other researchers, since it may provoke the use of more measures, though also carrying high benefits such as increased result validity. Hopefully, researchers' high self-control and curiosity will help resolve potential ambivalence thereby preventing them from engaging in excessive avoidance behavior or choice delay.

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Statement of Originality

Ich versichere, dass ich meine Dissertation „Ambivalence in Attitudes towards Robots“ selbstständig und ohne die Hilfe Dritter angefertigt habe. Alle Textstellen, die wörtlich oder sinngemäß anderen Quellen entstammen, habe ich als solche kenntlich gemacht. Die Dissertation wurde in der gegenwärtigen oder einer ähnlichen Fassung bei keiner anderen Hochschule eingereicht und hat keinem Prüfungszweck gedient.

Ort, Datum	Julia G. Stapels

Appendix

Stapels, J. G., & Eyssel, F. (Submitted for publication in *PloS ONE*). Torn between love and hate: Mouse tracking ambivalent attitudes towards robots.

Notes:

The following manuscript is reprinted as submitted to PloS ONE, except for the figures. The figures were added here for better readability since they were submitted separately in the journal's submission software. Page numbers are omitted in the following due to page numbers included in the manuscript. Further notes that were submitted separately in the submission software are as follows:

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The authors have declared that no competing interests exist.

This research was approved by the Ethics Committee of Bielefeld University (applications No. 2019-237 of 19/11/06 and No. 2020-094 of 20/06/15). Informed consent was obtained in written form (Experiment 1) and online (Experiments 2-4).

Keywords: robots; psychological attitudes; psychometrics; social cognition; decision making; human-robot interaction; mouse tracking; robotics; social psychology

Torn between love and hate: Mouse tracking ambivalent attitudes towards robots

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Abstract

Robots are a source of evaluative conflict and thus elicit ambivalence. In fact, psychological research has shown across domains that people indeed simultaneously report strong positive and strong negative evaluations about one and the same attitude object. In the current research, we extended such ambivalence research by measuring ambivalence towards various robot-related stimuli with explicit (i.e., self-report) and implicit measures. Concretely, we used a mouse tracking approach to gain insights into the experience and resolution of evaluative conflict elicited by robots. In an extended replication across four experiments with $N = 411$ overall including a meta-analysis, we showed that the amount of reported conflicting thoughts and feelings (i.e., objective ambivalence) and self-reported experienced conflict (i.e., subjective ambivalence) were consistently higher towards robot-related stimuli compared to univalent stimuli. Further, implicit measures of ambivalence revealed that response times were higher when evaluating robot-related stimuli compared to univalent stimuli, however results concerning behavioral indicators of ambivalence in mouse trajectories were inconsistent. This might indicate that behavioral indicators of ambivalence apparently depend on the respective robot-related stimulus. We could not obtain evidence of systematic information processing as a cognitive indicator of ambivalence, however, qualitative data suggested that participants might focus on especially strong arguments to compensate their experienced conflict. Furthermore, interindividual differences did not seem to substantially influence ambivalence towards robots. Taken together, the current work successfully applied the implicit and explicit measurement of ambivalent attitudes to the domain of social robotics while identifying potential boundaries for its applicability.

Introduction

The great "robot invasion" has been expected for decades [1]. Robots have been described as becoming "ubiquitious" in the near future (cf. [2–4]), but it is likely that we will wait some more decades to welcome robots as social interaction partners in our lives. Even if technological progress will enable the development of functional social robots, user reactions and attitudes are hard to predict. Potential users have high hopes for the use of robots [5]. These hopes can easily be crushed by incompetent robots and cause disappointment and a hesitation to use robots at all [6, 7]. Relatedly, users have serious and justified concerns for robot use, e.g., regarding security or privacy [8, 9]. As a potential reinforcement of such negative evaluations, robots are likely to be seen as an outgroup and are prone to suffer discrimination such as other discriminated groups [10, 11] and even bullying [12]. Such discrimination might in part be caused by evaluative conflict on the individual level, namely attitudinal ambivalence [13]. Potential robot users feel torn between aspirations and concerns associated with the use of social robots, resulting in ambivalent attitudes towards robots.

In the current work, we extended previous work that commonly assessed ambivalence towards robots using self-reports [13]. Therefore, we measured ambivalence explicitly via self-report and implicitly via mouse tracking towards a variety of robot-related stimuli, and investigated the cognitive and behavioral consequences. To do so, we first clarify the concept of ambivalence towards robots.

1 Related Work

1.1 Ambivalence towards Robots

Social psychological research has recently investigated ambivalence towards robots in general. Despite often being described as neutral, attitudes towards robots actually seem to be highly ambivalent [13]. That is, attitudes towards robots encompass strong positive and strong negative evaluations at the same time. Such ambivalent attitudes cause negative affect, and the experience of conflict and being torn between two sides of an attitude. In contrast, neutral attitudes imply weak positive and negative evaluations. As such, neutral attitudes do not cause strong affective responses. Previous research has shown that neutral and ambivalent attitudes can easily be confused, depending on the measurement method used [14]. The distinction between ambivalence and neutrality is practically relevant because of its affective and behavioral consequences, e.g., resulting in higher arousal or decision delay, which might practically result in potential users' reluctance to engage with robots at home. Previous research on ambivalence towards robots has predominantly relied on self-report measures concerning ambivalent attitudes and its affective consequences [13]. To extend this work, we apply a response-time-based method, measuring the magnitude and resolution of ambivalence implicitly and on a behavioral level. We thereby apply a theoretical framework that represents the affective, cognitive, and behavioral aspects of ambivalence, the "ABC of Ambivalence" by van Harreveld, Nohlen, and Schneider [15] to the domain of social robotics. According this model, subjective ambivalence, the subjective experience of conflicting evaluations, results in negative affect, since subjective ambivalence indicates an unpleasant state of conflict and arousal. Further, ambivalence can be observed in behavioral indicators (i.e., decision delay and motor behavior) and cognitive indicators (i.e., compensatory cognitions and systematic processing). In the current work, we aimed to replicate the findings concerning cognitive and behavioral indicators of ambivalence in the domain of social robotics, while extending the notion of interindividual differences in the experience of ambivalence.

1.2 Behavioral Indicators of Ambivalence

Ambivalence in attitudes influences behavior. Specifically, it causes choice delay and diverging motor behavior [15]. Tracking mouse trajectories represents a reliable method reflecting the decision-making process, measuring choice delay and implicit indicators of conflict in motor behavior [16]: In a common mouse tracking task, the mouse cursor is fixed at a starting point. Buttons in the top corners of the screen have to be reached to make an evaluation (e.g., "positive" and "negative"). A stimulus appears in the middle of the screen and participants are asked to quickly move the mouse to the answer button of their choice, while their trajectories are recorded. In addition to overall decision times, tracking mouse trajectories provides the opportunity to measure

"Maximum Deviation" (MD). During the evaluation task, when recording the path of the mouse cursor, MD indicates the point at which the trajectory deviates the most from an ideal path from the starting point to the chosen answer button. To illustrate, responses towards univalent stimuli usually follow a straight line, and ambivalent responses show a "pull" towards the non-chosen option [16] (see Fig 1). While response times *unspecifically* indicate overall decision difficulty or processing difficulty, MD *specifically* indicates attitudinal conflict [17]. In addition, MD-time can be assessed. This is the point in time at which the highest deviation from the direct cursor path occurs. MD-time can thus be interpreted as the moment of highest conflict, after which the experienced conflict is then resolved.

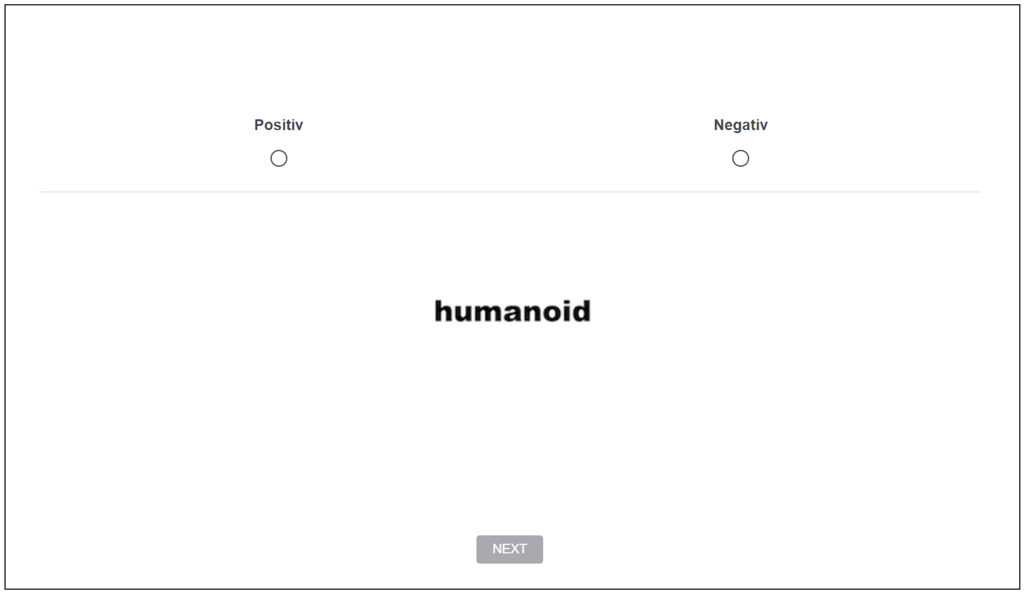

Fig 1. Screenshot of an example mouse tracking task. The mouse cursor starts on the next button and the participant moves it to one of the response buttons ("positive" and "negative", in German) during decision making.

To illustrate, Schneider and colleagues [17] have used mouse tracking to demonstrate longer response times (i.e., choice delay) during decision making concerning ambivalent stimuli. Choice delay is one indicator of evaluative conflict. Above and beyond, participants' mouse trajectories during a dichotomous decision-making task did not transfer to a straight line between the starting point and the response button. Instead, mouse movements deviated significantly from the straight line from starting point to answer button when attitudes were ambivalent (i.e., diverging motor behavior). That is, the feeling of being "torn" between positive and negative evaluations translated directly to mouse movements during the decision.

In the current research, we apply the mouse tracking methodology to the domain of social robotics as a tool to assess implicit behavioral measures of ambivalence. Further, we operationalized choice delay not only in terms of a delay in response times, but also in terms of a low score on an explicit behavioral measure, namely contact intentions. Contact intentions imply the readiness to meet and interact with robots.

1.3 Cognitive Indicators of Ambivalence

In addition to behavioral indicators, ambivalent attitudes are associated with specific cognitive indicators, distinguishing ambivalent from univalent or neutral attitudes.

Specifically, ambivalent attitudes are associated with systematic processing and compensatory cognitions [15]. Previous research has shown that ambivalence leads to systematic processing of attitude relevant information. This might result in seeking out further information about the attitude object in order to reduce ambivalence and come to a non-conflicted attitude [18]. People who hold univalent attitudes do not experience conflict. Accordingly, they might not feel the need to obtain further information on the attitude object. In contrast, individuals who hold ambivalent attitude are motivated to resolve their conflict, following consistency motives [19]. This attitudinal conflict can be resolved by obtaining further information on the respective attitude object. Therefore, people with ambivalent attitudes might welcome further information on an attitude object in order to resolve the unpleasant state of attitudinal conflict. Further, they might engage in compensatory cognitions, either concerning the attitude object itself, or in an unrelated manner. For example, concerning the attitude object itself, participants might specifically commit to one side of evaluations, to reduce conflict [15]. This process is called affirmation [20]. Affirmation can even be unrelated to the ambivalent attitude object concerning its content, such as compensating for the conflict by finding order in grainy images or even higher conspiracy beliefs [21].

1.4 Interindividual Differences

While ambivalence has certain behavioral and cognitive indicators, ambivalence itself is influenced by various interindividual differences.

1.4.1 Technology Commitment

Not everyone resolves evaluative conflict in the same way, since interindividual difference variables (i.e., attitudes, traits etc.) might play a role in conflict resolution. One of these interindividual differences is technology commitment, which might be specifically important concerning novel technologies such as robots. Technology commitment refers to people's general affinity and their ease of use of technology [22]. Previous research has provided evidence for the fact that people high in technology commitment feel less conflicted about robots [13]. It is therefore plausible that people high in technology commitment experience less conflict concerning robots overall, or, alternatively, they reach the point of highest conflict (MD-time) earlier in the decision making process, as measured via mouse tracking.

1.4.2 Self-control

Another interindividual difference that plays a role in conflict resolution is self-control. People high in self-control are more successful and better adjusted (e.g., less psychopathology, higher self-esteem, more optimal emotional responses) [23]. One reason for the positive effects of self-control is a more efficient conflict resolution, which may be helpful when resolving ambivalence. A meta-analysis has given an overview of the relationship between self-control and ambivalence [24]. Namely, self-control leads to an earlier moment of highest conflict (MD-time), but not to less conflict overall (MD), as measured via mouse tracking. That is, people high in self-control resolve attitudinal conflict earlier in the decision-making process. Therefore, self-control might also influence decision-making towards robots.

1.4.3 Proclivity to Anthropomorphize

Another construct that might be relevant for the evaluation of robots in particular concerns individuals' tendency to anthropomorphize nonhuman entities. This entails the attribution of humanlike characteristics to nonhuman entities [25]. The tendency to anthropomorphize likewise influences attitudes towards robots, especially increasing empathy and trust [26]. In the current research, we explored whether participants' tendency to anthropomorphize might influence the magnitude and resolution of attitudinal conflict. Specifically, participants with a high level of anthropomorphization proclivity might report more positive attitudes towards robots, since they see them as more human-like and therefore experience less conflict. However, the opposite mechanism is equally plausible, since a robot high in humanlikeness in terms of appearance or behavior might be perceived as both threatening and likeable at the same time. This, in turn, would increase ambivalent attitudes.

1.4.4 Big Five Factors of Personality

Finally, personality traits, such as the Big Five factors of personality (namely agreeableness, openness to experience, conscientiousness, neuroticism, and extraversion) might influence ambivalent attitudes towards robots. For instance, extraversion has been demonstrated to influence attitudes towards robots positively [27]. We explore possible relationships of the Big Five with ambivalence towards robots in the present research.

2 The Present Research

In the present work, we aimed to extend previous research concerning ambivalent attitudes towards robots by replicating it with various robot-related stimuli in four experiments. Further, we additionally investigated behavioral and cognitive indicators of ambivalence in attitudes towards robots with the help of self-report and response-time-based measures. This way, we tested the applicability of the ABC of Ambivalence [28] to the domain of social robotics as well as gain further detailed insight into ambivalent attitudes towards robots on the affective, behavioral, and cognitive level.

All four experiments were approved by the Ethics Committee of Bielefeld University (applications No. 2019-237 of 19/11/06 and No. 2020-094 of 20/06/15). For all four experiments presented in the following, we report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study or in the respective preregistrations. As effect sizes we report Cohen's d [29].

3 Experiment 1

In Experiment 1, we conducted a laboratory-based experiment, assessing ambivalence towards robot-related words reflecting robot categories and robot functions via self-report and mouse tracking. Furthermore, we explored the cognitive consequences of ambivalence towards robots qualitatively. We further investigated the role of the interindividual difference variables self-control and technology commitment in the experience and resolution of attitudinal ambivalence.

We used different types of robot-related words as stimuli, namely robot categories and robot functions) When investigating attitudes towards robots, it might be essential to specify the type of robot that is being investigated, since e.g., an industrial robot is fundamentally different in its functions and appearance from a social robot. Within Experiment 1, we examined five prominent robot categories (i.e., service robot, industrial robot, medical robot, exploration robot, social robot). Concerning robot functions, we investigated five defining functions of a social robot that is currently under development, namely the VIVA robot (https://navelrobotics.com/viva/). VIVA is a social robot for the home use which is able to carry out short conversations with the user, recognizes emotions and reacts accordingly, and plans and carries out actions autonomously [30, 31]. We investigated several robot functions since evaluations might differ greatly depending on the respective function, while all functions represent important aspects that constitute various autonomous robots (social function, personalizability, mobility, video function, voice control).

We assumed that ambivalence in attitudes towards robots would reflect in behavioral indications of evaluative conflict. Thus, as preregistered (https://aspredicted.org/x5qq9.pdf), we hypothesized that MD, as a measure of behavioral indicators of ambivalence, would be higher for robot stimuli compared to univalent stimuli (H1a, H1b). To replicate previous findings concerning self-reported ambivalence towards robots [13], we hypothesized that objective (H2) and subjective ambivalence (H3) would be higher for robot stimuli than for univalent stimuli. Moreover, to investigate the role of trait variables on the resolution of ambivalence, we hypothesized that participants high in technology commitment would experience less ambivalence overall, and thus, show lower MD (H4a). Finally, to investigate the influence of interindividual differences on the resolution of conflict, we assessed MD-time. MD-time was defined as the time-point of the highest deviation and thus, the highest conflict. This measure marked the time of conflict resolution, independent from the overall response-time. We hypothesized that participants high in technology commitment (H4b) or self-control (H5) would resolve their attitudinal conflict more quickly, and, in turn, would show lower MD-time.

- H1a: MD is higher for robot category stimuli compared to univalent stimuli.
- H1b: MD is higher for robot function stimuli compared to univalent stimuli.
- H2: Objective Ambivalence is higher for robot stimuli than for univalent stimuli.
- H3: Subjective Ambivalence is higher for robot stimuli than for univalent stimuli.
- H4a: Technology commitment would correlate negatively with MD.
- H4b: Technology commitment would correlate negatively with MD-time.
- H5: Self control would correlate negatively with MD-time.

3.1 Method

3.1.1 Participants and Design

118 participants were recruited at Bielefeld University to participate in a 15-minute laboratory study for a raffle of three 20€ vouchers or course credit, and sweets. As preregistered, we excluded 7 participants who failed the attention check, resulting in 111 valid cases (M_{age} = 23.11, SD_{age} = 3.79; 43 female, 57 male, 11 not specified). We employed a one-factorial within-participants design with two levels (stimulus type: robot stimuli vs. univalent stimuli).

3.1.2 Experimental Manipulation

We used ten univalent words (i.e., happy, holiday, in love (one word in German), sunshine, vegetable, abuse, depressed, disgust, unhappy, cockroach) based on previous research investigating ambivalence [17, 32]. For the robot conditions, we chose five robot category words that represent robot categories and five robot function words. For the robot categories, we chose five prominent robot categories (service robot, industrial robot, medical robot, exploration robot, social robot) and provided a short explanation for each. That is, the service robot was introduced as a robot providing service for people, the industrial robot as being able to handle and assemble work pieces, the medical robot as performing medical tasks, such as surgery, diagnostics and care, the exploration robot as being used in places that are dangerous for people, and the social robot as being capable of basic social interactions.

We chose the robot functions based qualitative data from a previous experiment [30]. Here, participants had indicated potential advantages and disadvantages of a social robot, which mainly concerned five functions of the robot (social function, personalizability, mobility, video function, voice control). We concluded that these functions seemed to be important for participants' evaluations of social robots and we therefore included them in the current research. To illustrate the practical significance of the functions, we introduced them with positive and negative remarks provided about the VIVA robot in a previous experiment [30].

We further included five ambivalent stimuli (i.e., abortion, organ donation, euthanasia, alcohol, candy [17, 32]) for exploratory reasons, however, they are not included in the hypotheses or results. Nevertheless, they are available in the provided dataset. In total, the experiment consisted of 25 trials, orienting on [17], who included between eight and 24 trials per experiment.

3.1.3 Measures

Unless otherwise indicated, self-report measures consist of seven-point scales ranged from "not at all" to "very".

Mouse Tracking. We assessed the magnitude of evaluative conflict by observing mouse trajectories during responding with the validated MouseTracker software [16]. Here, the path of the mouse cursor during the evaluation task is recorded, ranging from a set starting point to one of two choices (positive, negative). This path shows a stronger "pull" towards the non-chosen objects when evaluating ambivalent attitude objects, compared to univalent attitude objects, operationalized as MD [17]. In addition, response times were recorded as an indicator of choice delay, and MD-time was recorded as a an indicator of the point of highest conflict.

Subjective Ambivalence. We assessed subjective ambivalence towards each stimulus with one item reading 'To what degree do you experience conflicting thoughts and/or feelings?' The seven-point scale ranged from "no conflicting thoughts/feelings" to "completely conflicting thoughts/feelings", cf. [33].

Objective Ambivalence. We assessed objective ambivalence with two items, assessing the positive and the negative sides of the attitude separately, reading "How positive [negative] do you find this?". The values were integrated into a quantitative score of objective ambivalence using the following formula: $[(P + N)/2] - |P - N|$ [34]. P is substituted by the positive values and N by the negative values. Low values for both evaluation sides or for one evaluation side result in a low score, while high values for both evaluation sides result in a high score for objective ambivalence, indicating the objectively opposing evaluations with the potential to cause attitudinal conflict.

Technology Commitment. We assessed technology commitment with eight items (adapted by [35]; original version by [22]). The questionnaire features the sub-scales technology acceptance, e.g., "I like to use the newest technological devices.", and technology competence, e.g., "I find it difficult to deal with new technology." (reverse coded). The sub-scale technology control is not included in this version due to its lack of discriminant validity and internal consistency, cf. [22].

Self-Control. We assessed trait self-control with the Brief Self-Control Scale [23], consisting of 13 items, e.g., "I am good at resisting temptations.".

Qualitative Items. To extend our insights into potential users' specific evaluations regarding robots, we included three items in an open response format which were analyzed quantitatively. These items read "Which benefits and disadvantages of robots cause an inner conflict in you?" (open answer format), "Which robot function causes an inner conflict in you?" (six options with the presented robot functions, and the option "none"), "Why did you choose this function?" (open answer format), "Which robot categories causes an inner conflict in you?" (six options with the presented robot categories, and the option "none") and "Why did you choose this category?" (open answer format).

Demographics and Attention Check. We assessed gender, age, and German language skills. We included a check of data quality by asking participants whether they had participated meticulously.

3.1.4 Procedure

Participants were told that they would be asked for their opinion about a new social robot and robots in general. After reading the instructions and providing informed consent, participants were presented with an image and a short description of a social robot. After a first attention check asking for the name of the robot, they saw descriptions of five of its functions together with positive and negative statements about these functions that were collected from a previous study (see Table 1). We selected these functions, because qualitative results from a previous study indicated that participants hold positive as well as negative evaluations towards these functions [30]. We aimed to make this potential ambivalence salient by presenting the participants in this study with positive and negative aspects of the function, since people do not encounter robots in their daily lives [36], and might not have formed strong opinions yet about various robot functions. We randomized whether the positive or the negative statement was presented first. To introduce participants to various robot categories, participants were presented with five pictures of robot categories (i.e., service robot, industrial robot, medical robot, exploration robot, social robot) and a short description. To ensure attention, participants were told to memorize the descriptions for a subsequent memory task. In the memory task, participants were asked to pair the robot category with the right description. Then, participants completed the mouse tracking task, evaluating five positive, five negative, and five ambivalent stimuli, the five robot functions and the five robot categories as "positive" or "negative". Then, we presented all stimuli again and assessed self-reported objective and subjective ambivalence for each stimulus. Finally, we assessed self-control and technology commitment, qualitative questions, demographic data, and a final attention check. Participants were debriefed, thanked, and dismissed.

3.2 Results and Discussion

3.2.1 Main Analyses

Mouse Tracking. We conducted dependent t-tests with stimulus type as the independent variable to investigate the main hypotheses concerning MD as an indicator of ambivalence towards robots. MD was higher towards robot stimuli (M = 0.39, SD = 0.22), than towards univalent stimuli (M = 0.33, SD = 0.28, $t(108) = 2.15$, $p = .017$, d = 0.20; see Fig 2). When investigating the stimulus categories individually, contrary to our expectations (H1a), MD was not significantly higher towards robot category stimuli ($M = 0.37$, $SD = 0.24$) than towards univalent stimuli ($t(110) = 1.45$, $p = 0.075$, $d = 0.14$). However, in line with our hypothesis (H1b), MD was higher towards robot function stimuli ($M = 0.40$, $SD = 0.29$) than towards univalent stimuli ($t(108) = 2.17$, $p = .016$, $d = .20$). This indicates a small effect size, which might be observed more consistently with larger sample sizes. Moreover, the lack of a significant difference in MD between univalent stimuli and robot category stimuli could be due to a lack of information about the presented robot categories. When a limited amount of information is accessible, attitudes might tend to be ambiguous, rather than ambivalent, potentially resulting in less evaluative conflict. Concerning the robot category stimuli, participants were provided with a picture and a short description of the robot, while for the robot function stimuli, they were provided with pro and con arguments from peers. This way, ambivalence might have been more successfully induced towards robot functions, compared to robot categories.

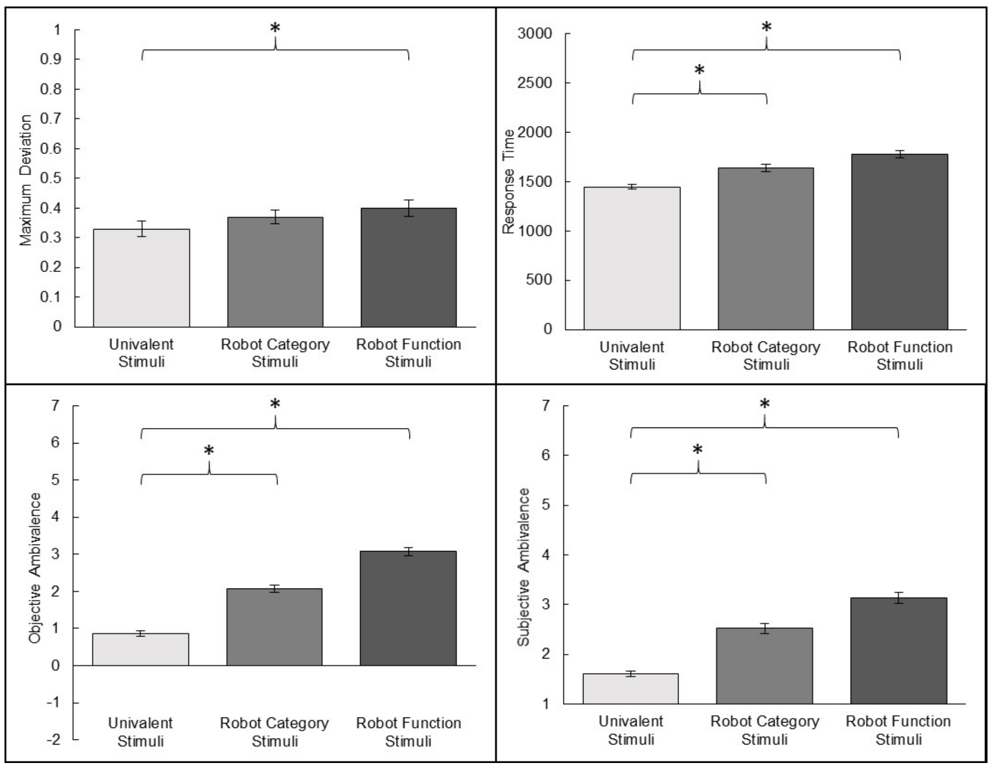

Fig 2. Means, standard errors and statistical significance of maximum deviation, response time, objective ambivalence and subjective ambivalence for each condition in Experiment 1.

Furthermore, in line with previous work (e.g., [17,28]) overall response times were higher when evaluating robot-related stimuli ($M = 1701.36$, $SD = 364.95$) compared to univalent stimuli ($M = 1444.46$ $SD = 251.48$, $t(108) = 10.34$, $p < .001$, $d = 0.71$). This was the case for both robot category stimuli ($M = 1637.91$, $SD = 361.44$; $t(110) = 7.46$, $p < .001$, $d = 0.58$) as well as robot function-related stimuli ($M = 1777.48$, $SD = 414.43$; $t(108) = 11.31$, $p < .001$, $d = 0.74$), indicating medium to large effect sizes. Response times might be used as an additional parameter to reflect choice delay caused by ambivalence. However, they should be interpreted with caution, since robot words, despite having been introduced in the beginning of the experiment, might be less familiar to most participants compared to the univalent words that are often used in everyday life and they therefore might process the respective information slower and respond later.

Self-Report Measures. To ensure the convergent validity of the mouse tracking measurement, we also investigated self-reported ambivalence towards robots. In line with previous research [13], objective ambivalence was higher towards robot stimuli (M = 2.57, SD = 1.01) than towards univalent stimuli (M = 0.86, SD = 0.70), $t(110)$ = 17.47, $p < .001$, d = .86; (H2). Both, robot categories (M = 2.07, SD = 1.06; ; t = 11.65, $p < .001$, d = .74) and robot functions (M = 3.07, 1.24, ; t = 18.83, $p < .001$, d = .87) evoked higher objective ambivalence than univalent stimuli, with large effect sizes. Furthermore, self-reported subjective ambivalence was higher towards robots (M = 2.82, SD = 0.97) than towards univalent stimuli (M = 1.60, SD = 0.61), $t(110)$ = 14.16, $p < .001$, d = .80 (H3), indicating a large effect size. Both, robot categories (M = 2.52 SD = 1.02; $t(110)$ = 11.65, $p < .001$, d = 0.74) and robot functions (M = 3.13, SD = 1.13; $t(110)$ = 18.83, $p < .001$, d = 0.87) evoked higher subjective ambivalence than univalent stimuli, indicating medium to large effect sizes. These large differences in self-reported ambivalence did apparently not directly translate to diverging motor behavior. We discuss possible causes in the General Discussion section.

3.2.2 Interindividual Differences

To investigate the influence of interindividual differences on conflict resolution, we ran correlations between technology commitment (M = 4.98, SD = 1.10, α = .80) and self-control (M = 4.23, SD = 0.98, α = .83) with mouse tracking data in robot-related trials. As predicted, technology commitment correlated moderately negatively with MD ($r(106)$ = -.35, $p < .001$). That is, people high in technology commitment experienced less conflict overall, compared to people low in technology commitment (H4a). Also, technology commitment correlated negatively with MD-time($r(106)$ = -.21, p = .028; H4b). This indicates that people high in technology commitment experience less ambivalence and also resolve ambivalence earlier in the decision making process compared to people low in technology commitment. However, contrary to our expectations, self-control ($r(106)$ = .03, p = .786; H5) did not significantly correlate with MD-time. That is, in this case, people high in self-control did not reach the moment of highest conflict, and thus, conflict resolution earlier than people low in the respective traits (cf. [24]).

3.2.3 Qualitative Data

To gain more detailed insights into the actual contents that might cause ambivalence towards robots, we had recorded evaluation contents in an open format. In this qualitative part of the experiment, we asked participants which robot functions would elicit attitudinal conflict. Participants provided 345 evaluations in total. Those evaluations were categorized by two raters into 18 categories, namely 8 assets (i.e., assistance, companionship, entertainment, usability, personalization, information, status, surveillance) and 9 risks (i.e., privacy, isolation, data security, discomfort, trouble, loss of autonomy, realistic threat, inhumanity, abuse, resources; based on [30]). The concern that robots could take over humans' jobs was voiced frequently, so we created an additional risk category (i.e., steal jobs). The most frequently voiced assets were assistance (82 mentions, e.g. "help in everyday life"), companionship (12 mentions, e.g. "social contact for lonely people"), and usability (14 mentions, e.g."easy to use"). The most frequently voiced risks were privacy and data security concerns (57 mentions, e.g."violation of privacy"), the fear of social contact being replaced by robots (33 mentions, e.g., "neglecting social interaction") or robots taking over jobs (32 mentions, e.g., "can take jobs from humans"). In the ABC of Ambivalence [15], one of the cognitive consequences of ambivalence is engaging in compensatory cognitions. That is, participants try to attenuate experienced conflict by compensating via related cognition (e.g., focusing on one side of the argument) or even unrelated cognitions (e.g., finding order in snowy pictures or showing higher belief in conspiracy theories). In current data, we find exploratory indication of compensatory cognitions: Data revealed that people might be prone to resolve their conflict by especially strong arguments, such as "no matter how useful the robot is, I don't want to use it if my data are not safe" or "technologies are useless if people suffer". However, this interpretation is purely exploratory and might be investigated on a quantitative level in future experiments.

4 Experiments 2-4

Experiments 2 to 4 were conducted online due to restrictions to perform laboratory experiments caused by the COVID-19 pandemic. Since the original software was not compatible for the online use, we conducted Experiments 2-4 with a new Qualtrics package software by [37].

In these experiments, we aimed to establish the main effect of robot related stimuli on MD as a behavioral indicator of ambivalence. We measured ambivalence via mouse tracking and self-report concerning various robot pictures and words. We further investigated the behavioral and cognitive indicators of ambivalence through measuring contact intentions towards robots and interest in further information on robots (information search). The preregistered hypotheses (https://aspredicted.org/4p3zh.pdf) for Experiments 2 to 4 were as follows:

- H1: MD is higher for robot stimuli than for univalent stimuli.
- H2: MD predicts lower contact intentions.
- H3: MD predicts extended information search.
- H4: Technology commitment correlates negatively with MD.

The required sample size was computed using G*Power [38]. A power analysis for a one sided t-test for H1 expecting a medium effect ($d = 0.5$, $\alpha = 0.05$, $\beta = 0.95$) revealed a required sample size of 45. A further analysis for correlations for H2-4 ($r = 0.35$, $\alpha = 0.05$, $\beta = 0.95$) revealed a required participant size of 100 per experiment. We therefore preregistered a sample size of 100, respectively.

5 Experiment 2

In Experiment 2, we investigated the behavioral and cognitive indicators of ambivalence towards robots by using robot-related words, while exploring interindividual differences in the experience of ambivalence.

5.1 Method

5.1.1 Participants and Design

171 complete datasets were collected in a 15-minute online experiment for a raffle of three 10€ vouchers or course credit. As preregistered, we excluded data from participants who indicated not having participated meticulously (16 datasets) and not having used a mouse in the evaluation task (51 datasets). While participants using a touchscreen were excluded since it can not trace the path of the mouse, we also

excluded participants using a mouse pad, to keep the experimental conditions as similar as possible to Experiment 1. Invalid mouse Tracking responses were excluded as specified in the mouse tracking software (3 datasets), and not responses by participants not speaking German fluently (0 datasets). From the remaining 101 datasets, the last one was excluded to reach the preregistered sample of 100 datasets ($M_{age} = 33.87$, $SD_{age} = 14.90$, 59 female, 38 male, 1 diverse, 2 not specified). 53 participants were students, 29 were employed, 5 were self-employed, 1 was unemployed, 4 were retired and 8 were not specified.

5.1.2 Experimental Manipulation

We used six univalent words from Experiment 1 (i.e., disgust, abuse, unhappy, happy, holiday, sunshine) and six robot-related words (i.e., android, humanoid, robot, robotics, robotic, robot-like). All stimuli consisted of one word in German, respectively. This resulted in a total of twelve trials.

5.1.3 Measures

Mouse Tracking. With the new online mouse tracking package for Qualtrics [37] Maximum Deviation and response times were recorded while MD-time could not be obtained. Further measures automatically recorded by the software were not used in the current experiments.

Self-Report Measures. We used the same self-report measures as in Experiment 1 to assess subjective ambivalence, objective ambivalence, and technology commitment. We measured contact intentions towards robots through the mean of five items that assess the willingness to interact with a robot in general, adapted from [39]. E.g., we adapted the item "How much would you like to meet the robot?" to read "How much would you like to meet a robot?". Further, we assessed behavioral intentions to seek out further information about robots (information search) through the mean of four items (adapted from [18]), e.g., "To what degree are you curious about robots?". For exploratory purposes, we further assessed the Big Five factors of personality with a short scale consisting of ten items from [40] and the tendency to anthropomorphize with a scale of 15 items by [25].

5.1.4 Procedure

Participants were asked to evaluate several words as positive or negative and they were informed that their mouse movements would be recorded during the evaluations. After the practice trials, in the experimental trials participants evaluated all attitude objects as positive or negative in a random order. Participants then completed the measures of subjective and objective ambivalence for each item. Subsequently, they filled out the measures of contact intentions and information search. Finally, the Big Five factors of personality, proclivity to anthropomorphize, and technology commitment items were presented, participants completed the attention check and indicated their demographic data.

5.2 Results and Discussion

5.2.1 Main Analyses

Mouse Tracking. As predicted, MD was higher in the robot condition ($M = 0.93$, $SD = 0.43$) than in the univalent condition ($M = 0.68$, $SD = 0.43$), $t(99) = 5.28$, $p < .001$, $d = 0.53$, indicating a medium effect size (H1; see Fig 3). As in Experiment 1, response times were higher concerning robot words (M = 1761.32, SD = 532.05) compared to univalent words (M = 1298.16, SD = 361.66), $t(99) = 7.94$, $p < .001$, d = 0.79, indicating a medium to large effect size. Therefore, participants showed different motor behavior, operationalized through MD, as well as choice delay via response times when evaluating robot stimuli compared to ambivalent stimuli.

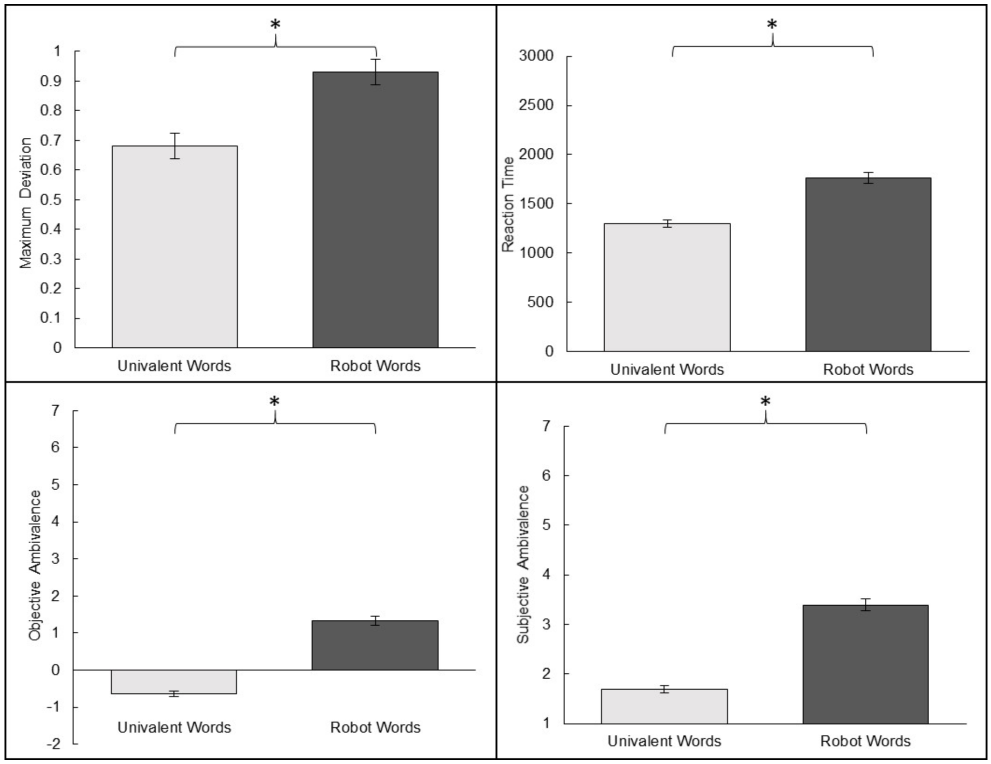

Fig 3. Means, standard errors and statistical significance of maximum deviation, response time, objective ambivalence and subjective ambivalence for each condition in Experiment 2.

To test Hypothesis 2 (H2), we used a regression analysis to investigate whether MD would predict contact intentions (M = 3.32, SD = 1.56, α = 0.82) towards robots. This was not the case: β = -0.02, $t(98)$ = -0.82, p = .413, R^2 = .01. Concerning our third hypothesis, MD did also not significantly predict information search (M = 3.67, SD = 1.73, α = 0.92), β = -0.04, $t(98)$ = -1.76 p = .081, R^2 = .03 (H3). Consequently, MD as an behavioral indicator of ambivalence was not predictive of the usual cognitive consequences of ambivalent attitudes in this experiment. For the fourth hypothesis (H4), we tested whether technology commitment (M = 4.72, SD = 1.15, α = .86) would correlate negatively with MD measured in robot evaluation tasks, like in Experiment 1. This was not the case $r(98)$ = .12, p = .235 (H4). Therefore, we found no evidence in this experiment indicating that participants high in technology commitment would experience particularly low ambivalence.

Self-Report Measures. In Experiment 2, objective ambivalence was higher in the robot condition (M = 1.32, SD = 1.25) than in the univalent condition (M = -0.64, SD = 0.80), $t(99)$ = 12.55, $p < .001$, d = 1.25. Subjective ambivalence was also higher in the robot condition (M = 3.39, SD = 1.22) than in the univalent condition (M = 1.69, SD = 0.74), t = 11.83, $p < .001$, d = 1.18. That is, robot stimuli evoked higher objective and subjective ambivalence compared to univalent stimuli, indicating large effect sizes.

Secondary Analyses. In order to explore the impact of interindividual differences on the experience of ambivalence, we analyzed correlation patterns between measures of ambivalence and the tendency to anthropomorphize and the Big Five factors of personality using Pearson's correlations. Tendency to anthropomorphize (M = 2.5, SD = 0.88, α = .88) did not significantly correlate with MD towards robots $r(98)$ = -0.19, p = .062. Neither did openness (M = 3.04, SD = 0.55, $r(98)$ = .05, p = .656), conscientiousness (M = 3.37, SD = 0.64, $r(98)$ = -0.15, p = .148), neuroticism (M = 2.96, SD = 0.79, $r(98)$ = -0.10, p = .327), agreeableness (M = 2.95, SD = 0.65, $r(98)$ = -0.07, p = .459), or extraversion (M = 3.06, SD = 0.49, $r(98)$ = -0.02, p = .878). To conclude, in Experiment 2, response time based mouse tracking data were statistically unrelated with the interindividual difference measures.

6 Experiment 3

With Experiment 3, we replicated and extended Experiments 1 and 2. We did so by using pictures as stimulus materials instead of words as in Experiments 1 and 2. Concretely, we utilized pictures depicting two robot categories, namely machine-like robots and humanoid robots. We chose these particular categories because they reflect a broad spectrum from robots that merely resemble appliances to robots that resemble humans. We presume that these different robot types likely evoke diverging evaluations. Moreover, We included these distinct robot categories to follow up on Experiment 1. Here, robot category words did not evoke higher MD compared to univalent stimuli. We will test whether this will also be the case when comparing machine-like vs. humanoid robots. Again, we considered self-reported ambivalence, technology commitment, and the tendency to anthropomorphize.

6.1 Method

6.1.1 Participants and Design

161 complete data sets were collected in a 15 minute online experiment for a raffle of three 10 € vouchers or course credit. As preregistered, we stopped data collection when 100 complete datasets (M_{age} = 27.62, SD_{age}= 8.43, 65 female, 35 male) were collected after excluding data as in Experiment 2. We excluded data from participants who indicated not having participated meticulously (8 datasets), not having used a mouse in the evaluation task (38 datasets), and not speaking German fluently (1 dataset). Invalid mouse Tracking responses were excluded as specified in the mouse tracking software (13 datasets). From the remaining 101 datasets, the last one was excluded to reach the preregistered sample of 100 datasets. Of the remaining 100 participants, 74 participants were students, 21 were employed, 2 were self-employed, 2 were unemployed and 1 was not specified.

6.1.2 Experimental Manipulation

In Experiment 3, participants were presented with 5 univalent pictures and 10 robot pictures. The univalent pictures depicted a cockroach ("cockroach 4"), a coffee ("coffee 1"), a rubber duck ("rubber duck 1"), a fence ("fence 2"), and weapons ("gun 6") from the open affective standardized image set (OASIS) [41], that were unequivocally positive or negative. The robot pictures were separated in two categories: five machine-like robots (Versatrax by Inuktun Services, Packbot by FLIR Systems, Phantom by DJI, Quince by Chiba Institute of Tech. and Tohoku University, and Spirit by NASA Jet

Propulsion Laboratory) and five humanoid robots (HRP-4C by AIST, Kaspar by University of Hertfordshire, Sophia by Hanson Robotics, and Geminoid F and Geminoid HI by Osaka University, ATR, and Kokoro,). All robot pictures used in Experiment 3 can be obtained at https://robots.ieee.org/ or upon request from the authors. In total, all participants evaluated 15 stimuli.

6.1.3 Measures

We employed the same measures for mouse tracking and self-reports as in Experiment 2, but in Experiment 3, we refrained from assessing the Big Five factors of personality.

6.1.4 Procedure

As in Experiment 2, after providing informed consent and being informed about the purpose of the study, participants evaluated all stimuli as positive or negative in the mouse tracking task. Then they completed the self-report scales, the attention check, and reported demographic information.

6.2 Results and Discussion

6.2.1 Main Analyses

Mouse Tracking. In line with Experiments 1 and 2, we had predicted that MD would be higher for robot stimuli compared to univalent stimuli (H1). We created a robot condition as the mean MD from all ten robot-related stimuli. Contrary to our predictions, MD was not higher for robot pictures ($M = 0.63$, $SD = 0.51$) compared to univalent pictures ($M = 0.61$, $SD = 0.33$), $t(99) = 0.53$ $p = .298$, $d = .05$ (see Fig 4). When analyzing the robot categories independently, MD was not higher for humanoid robot pictures ($M = 0.53$, $SD = 0.40$; $t(99)$ = -2.01, $p = .976$, $d = 0.2$) compared to univalent pictures. Surprisingly, MD was even lower for humanoid robots, although the difference was not significant. However, MD was significantly higher concerning machine-like robot pictures ($M = 0.78$, $SD = 0.58$; $t(99) = 1.79$, $p = .040$, $d = 0.18$) compared to univalent pictures, indicating a small effect size. In the current experiment, our main hypothesis could only be confirmed for part of the robot stimuli, namely the machine-like robots. The humanoid robots did not evoke higher maximum deviation compared to univalent stimuli. One explanation for the surprising results concerning the humanoid robot stimuli might be the *Uncanny Valley* Phenomenon [42], a strong negative, affective response when a robot approaches human-likeness but does not fully reach it. This negative response might have dominated the evaluation, overriding potential motor behavior indicating ambivalence.

Moreover, we analyzed response time data as indicators of choice delay. Overall, response times were higher for robot pictures ($M = 1402.49$, $SD = 648.42$) compared to univalent pictures ($M = 975.19$, $SD = 360.61$, $t(99) = 9.12$, $p < .001$, $d = 0.91$). This was the case for both humanoid robot pictures ($M = 1289.55$, $SD = 520.20$; $t(99) = 7.81$, $p < .001$, $d = 0.78$), as well as machine-like robot pictures ($M = 1515.42$, $SD = 756.66$; $t(99) = 7.49$, $p < .001$, $d = 0.75$), indicating large effect sizes. Taken together, these results indicate that evaluations of humanoid robot pictures partly resemble evaluations concerning univalent pictures: Mouse trajectories during the evaluation of humanoid robot pictures also did not deviate significantly from a direct path to the response button. However, these trajectories also resemble ambivalent evaluations in terms of higher response times. One reason for the high response times might be that the robot's eeriness prompted an initial, intuitive and straight, negative response, which was reevaluated consciously. This reevaluation might take up additional time in the decision making process. As in Experiment 2, MD did not significantly predict contact

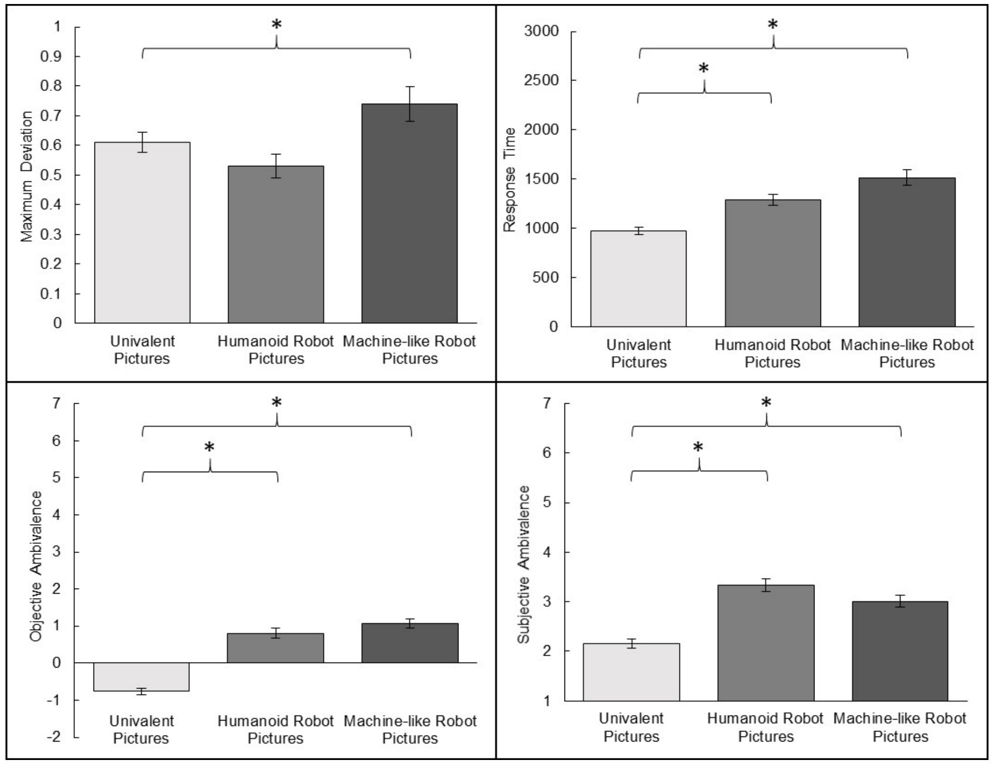

Fig 4. Means, standard errors and statistical significance of maximum deviation, response time, objective ambivalence and subjective ambivalence for each condition in Experiment 3.

intentions (M = 3.40, SD = 1.73, α = .91), $\beta < 0.01$, $t(98) = 0.07$, p = .947, $R^2 < .001$ (H2) or information search (M = 4.11, SD = 1.60, α = .91), $\beta = 0.01$, $t(98) = 0.39$ p = .701, R^2 = .001 (H3). As in Experiment 2, contrary to our predictions, technology commitment (M = 4.95, SD = 1.05, α = .84) did not correlate significantly with MD, $r(98) = .01$, p = .957 (H4). Therefore, Hypotheses 2, 3, and 4 could not be confirmed.

Self-Report Measures. Similar to the pattern of results from Experiments 1 and 2, findings from Experiment 3 revealed that objective ambivalence was higher in the robot condition (M = 0.94, SD = 1.06) than in the univalent condition (M = -0.76, SD = 0.88), $t(99) = 13.83$, $p < .001$, d = 1.38. Specifically, objective ambivalence was higher for both humanoid robot pictures (M = 0.80, SD = 1.37; $t(99) = 10.64$, $p < .001$, d = 1.06) as well as machine-like robot pictures (M = 1.08, SD = 1.23; $t(99) = 12.85$, $p <$ .001, d = 1.29), indicating large effect sizes. Moreover, self-reported subjective ambivalence was higher in the robot condition (M = 3.17 SD = 1.02) than in the univalent condition (M = 2.15, SD = 0.92), t = 8.64, $p < .001$, d = 0.86. Specifically, subjective ambivalence was higher for both humanoid robot pictures (M = 3.33, SD = 1.29; $t(99) = 8.97$, $p < .001$, d = 0.90) as well as machine-like robot pictures (M = 3.01, SD = 1.16; $t(99) = 6.02$, $p < .001$, d = 0.60), indicating medium to large effect sizes.

6.2.2 Secondary Analyses

Proclivity to anthropomorphize (M = 2.93, SD = 0.94, α = .88) did not correlate with MD ($r(98) = 0.02$, p = .839), as in Experiment 2. That is, we again did not find any indication of a connection between interindividual differences and motor behavior.

7 Experiment 4

In Experiment 4, we replicated and extended our work to yet another group of stimuli, namely various social robot *pictures*.

7.1 Method

7.1.1 Participants and Design

121 complete datasets were collected in a 15-minute online experiment for a raffle of three 10€ vouchers or course credit. As preregistered, we stopped data collection when 100 datasets (M_{age} = 29.02, SD_{age} = 13.03, 61 female, 39 male) were collected, after excluding data. Specifically, we had preregistered to exclude data from participants who had either indicated not having participated meticulously (0 datasets), not having used a mouse in the evaluation task (17 datasets), and not speaking German fluently (0 datasets). From the remaining 103 datasets, the last three were excluded to reach the preregistered sample of 100 datasets. Seventy-one participants were students, 20 participants were employed, 4 individuals were self-employed, one participant reported being unemployed, 2 people were retired, and one individual did not specify a response.

7.1.2 Experimental Manipulation

In Experiment 4, participants were shown five univalent pictures depicting swans ("bird 1"), a cat ("cat 4"), flowers ("flowers 2"), a fence ("prison 2"), and a toilet ("toilet 4") from [41]) and five pictures of social robots (Sophia and Zeno by Hanson Robotics, Pepper by Softbank Robotics, VIVA by Navel Robotics, and Kobian developed at Waseda University in Japan). Robot pictures used in Experiment 4 can be obtained at https://robots.ieee.org/ or upon request from the authors. We chose social robots as stimulus materials in this experiment, since this category follows up the robot functions from Experiment 1. In total, all participants evaluated ten stimuli.

7.1.3 Measures and Procedure

The procedure for Experiment 4 was identical to Experiment 3. However, unfortunately, due to a technical error no MD and response time data were collected. Nonetheless, we report the available self-report results for Experiment 4 here to complement the series of experiments.

7.2 Results and Discussion

Due to the technical failure in measuring mouse tracking, Hypotheses 1-4 which were related to MD could not be tested. However, fortunately, self-report data were recorded: In line with Experiments 1-3, self-reported objective ambivalence was higher in the robot condition (M = 0.90, SD = 0.96) than in the univalent condition (M = -1.10, SD = 0.90), $t(99)$ = 17.77, $p < .001$, d = 1.78 (see Fig 5).

Further, subjective ambivalence was higher in the robot condition (M = 3.41 SD = 1.10) than in the univalent condition (M = 1.67, SD = 0.70), $t(99)$ = 16.58, $p < .001$, d = 1.66, indicating large effect sizes. Experiment 4 thus extended the array of stimuli used in this set of studies to pictures of social robots. In contrast to the humanoid robot pictures in Experiment 3, the social robots in Experiment 4 consisted of various appearances, ranging from a very human-like Sophia robot to a cartoon-like Pepper robot. Participants seemed to hold opposing evaluations and feel conflicted towards social robots. Whether this self-reported ambivalence would reflect implicitly in mouse tracking might be investigated in future experiments.

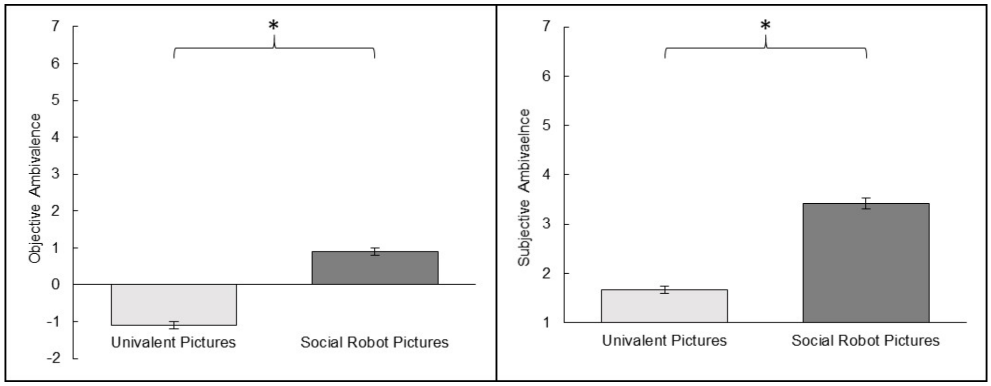

Fig 5. Means, standard errors and statistical significance of maximum deviation, response time, objective ambivalence and subjective ambivalence for each condition in Experiment 4.

8 Meta Analysis of Experiment 1-4

In the current experiments, self-reported ambivalence did not consistently translate to mouse tracking data as a behavioral indicator of ambivalence: Specifically, in Experiment 1, MD was higher concerning robot function words but not robot category words compared to univalent words. In Experiment 2, MD was higher concerning general robot words compared to univalent words, and in Experiment 3, MD was higher towards machine-like robot pictures but not humanoid robot pictures compared to univalent pictures. To explore the inconsistent findings regarding MD across experiments we conducted a meta analysis of the observed effects in Experiment 1-3 using the metafor package in R [43]. The meta analysis estimated a model with a standardized mean difference of -0.29 [-0.59, 0.02] (see Fig 6). This indicates the absence of an overall effect. Therefore, robots in general might not evoke higher MD compared to univalent stimuli. This is interesting, since all robot stimuli evoked responses that translated to medium to large effect sizes on self-reported ambivalence. It seems to depend on the specific stimulus type, whether such self-reported ambivalence translates to behavioral consequences, which we found for robot functions and machine-like robots. Overall, we observed a high variability across experiments concerning MD, and further research is necessary to investigate the specific stimulus characteristics, e.g., robot type, that lead to MD as a behavioral indicator of ambivalence.

9 General Discussion

The aim of the current research was to investigate ambivalence in a multi-faceted manner, taking into account the affective, behavioral, and cognitive dimension in explicit and implicit measures. In four experiments, we investigated self-reported objective and subjective ambivalence. To reflect behavioral indicators of ambivalence, we assessed MD and response times in Experiments 1 to 3, extended by contact intentions in Experiments 2 to 4. Further we assessed compensatory cognitions in Experiment 1 and systematic processing in Experiment 2 to 4 as cognitive indicators of ambivalence. As a similarity in all four experiments, we found that self-reported objective and subjective ambivalence was higher for various robotic stimuli compared to univalent stimuli. Large effect sizes underline the practical relevance of the observed effects. Participants seem to have competing positive and negative evaluations, as well as feeling torn between the positive and negative aspects of robots concerning robot function words, robot category

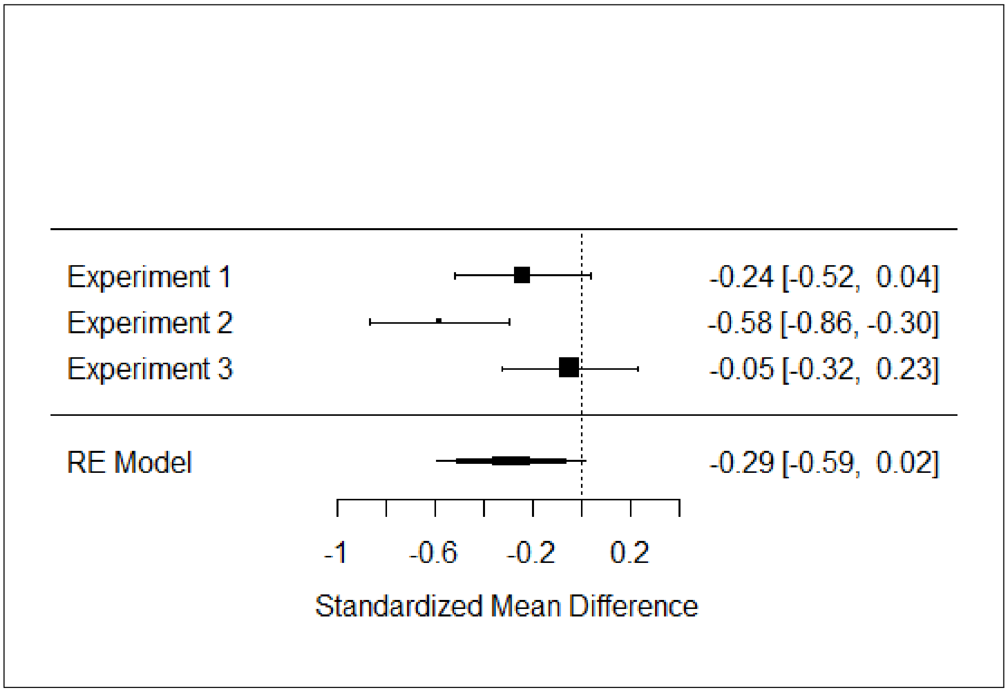

Fig 6. Meta Analysis of the effect of stimulus type (robot vs univalent) on MD in Experiments 1 - 3.

words, general robot words, humanoid robot pictures, machine-like robot pictures, and various social robot pictures. This underlines the generalizability of previous results (i.e., [13]) and emphasizes that all sorts of robots evoke high levels of evaluative conflict, namely ambivalence. However, self-reported ambivalence did not consistently translate to behavioral indicators of ambivalence, as measured via MD.

Our hypotheses concerning motor behavior were confirmed in one of three experiments concerning words related to robots in general (Experiment 2), while choice delay was consistently higher concerning robotic stimuli compared to univalent stimuli in all three mouse tracking experiments (Experiments 1 to 3). In two further experiments, the main hypothesis was confirmed only for a part of the stimuli, namely robot functions (Experiment 1), and pictures of machine-like robots (Experiment 3). Also in Experiment 3, it was especially surprising, that participants showed particularly low behavioral ambivalence (measured via MD) concerning humanoid robot pictures. One possible explanation might be an uncanny valley phenomenon, describing the effect that nonhuman entities are evaluated more favourably when they are more human-like, but seem eerie and uncanny of robots approaching human-likeness but do not completely achieving it [42]. In the literature, the role of the uncanny valley in the evaluation process has not yet been thoroughly investigated and does not seem to fit the originally proposed cubic function between human-likeness and evaluations [44]. In the current work, participants might have experienced an initial negative response towards pictures of humanoid robots, strongly affecting the evaluative conflict. Observing the evaluation process further via mouse tracking might provide valuable insights for roboticists into the specific cognitive and behavioral implications of the uncanny valley during decision making.

Contrary to our hypotheses, MD as an indicator of ambivalence did not predict systematic processing and interest in further attitude-relevant information across three experiments. Therefore, in the case of robots, experienced conflict might not be the most important factor when deciding whether to seek contact or information on robots. External factors such as the availability, price, or usability might be more important for robot contact in everyday life at the moment. However, qualitative data in Experiment 1 suggested that participants might engage in compensatory cognitions, which should be investigated further. Engaging in cognitions that enable a feeling of order is one strategy to cope with attitudinal conflict. Further studies might investigate, whether related or unrelated compensatory cognitions, e.g., finding order in snowy pictures [21], might help potential users cope with robot-related ambivalence.

Finally, in contrast to earlier work [30], participants high in technology commitment did not experience less ambivalence overall in Experiments 2 to 4. Neither the Big Five Factors nor interindividual differences in the proclivity to anthropomorphize correlated with ambivalence as measured by means of mouse tracking and self-reports. Accordingly, the investigated interindividual differences might not be connected with behavioral indicators of ambivalent attitudes towards robots. However, it should be noted that the power in the current experiments might have been too low to detect small effects of interindividual differences on ambivalence.

9.1 Strengths and Limitations

Conducting a four-experiment series comes both with a range of methodological assets and challenges. The current research is programmatic, experimental and the empirical approach enabled us to inquire the validity and generalizability of our results. This was due to the variety of stimuli employed and the replication of results across studies. In a mixed-methods approach, we combined explicit and implicit measures of ambivalence towards robots through including self-report and response time based data and extended the notion of ambivalence in attitudes towards robots through qualitative results. We explored the connection between interindividual differences and behavioral indicators of ambivalence, with scales of acceptable to high internal consistency. However, we did not obtain consistent significant correlations between interindividual differences and ambivalence. Furthermore, in line with the notions of open science and reproducibility, all four experiments were preregistered and data and code are available. The inconsistent results in behavioral measures underline the importance of replication in both psychological and social robotics research. While Experiment 2 alone would have provided convincing data regarding MD as a behavioral indicator of ambivalence towards robots, the variability of stimuli used in this series of experiment showed that the external validity of single experiments might be limited. It further demonstrated that explicit measures of ambivalence do not always transfer to implicit measures of ambivalence, and that the correlation might depend on stimulus type. With a replication approach, one can strengthen the confidence in results that are evident repeatedly and identify potential incidental findings, that only appear once. The current work contributes to social robotics research by providing examples of using social psychological methodology and theory to further our understanding of attitudes towards robots, integrating explicit and implicit measures. It furthermore contributes to social psychological research by applying fundamental research on ambivalent attitudes to a novel and practically relevant topic, namely social robotics.

Despite our focus on replicability and reproducibility, we also had to face methodological challenges. Due to the contact restrictions caused by the COVID-19 pandemic, laboratory experiments were not possible for Experiments 2 to 4. Switching mouse tracking software had several implications: First, the comparability between experiments is limited due to the different methods. Further, online mouse tracking produces more noise and data exclusions than mouse tracking in the laboratory due to diverging devices and uncontrollable environments. We hoped to counterbalance these restrictions using our replication approach and a large overall sample of 411 participants.

However, for future experiments, laboratory settings are preferred to eliminate as much variance that is unrelated to the investigated effect as possible.

Another limitation of the current work is the limited practical relevance of participants decisions, which might have particularly influenced the cognitive consequences of ambivalence. Previous research has indicated that ambivalence is especially strong, when the a relevant decision has to be made [45]. Since participants in the current experiments had no possibility to meet either of the presented robots, they might not have felt the decision to be important for their individual lives and might therefore not have been motivated to reduce their experienced ambivalence by cognitive strategies. Future studies might replicate the proposed methodology using robots that participants encounter in a research environment, while including a practically relevant decision, for example whether participants would like to speak to the robot, and track mouse trajectories in the meantime.

9.2 Future Work

In the current work, some indicators of ambivalence were consistently higher towards robot-related stimuli (objective and subjective ambivalence, response times), whereas MD as an implicit indicator of ambivalence yielded inconsistent results. To understand the connection between explicit and implicit measures of ambivalence towards robots, further categories of robot stimuli might be investigated with the proposed methodology, e.g., education robots or telepresence robots. Moreover, further knowledge concerning the uncanny valley effect might be gained with the use of mouse tracking methodology, since supposedly uncanny humanoid robots elicited surprising results in the current work.

As we did not find any indication of cognitive or behavioral consequences (i.e., information search, contact intentions) being influenced by MD in Experiments 2 to 4, future studies might investigate further variables derived from the components of the ABC of Ambivalence, such as unrelated compensatory cognitions or long term behavioral consequences, such as avoidance behavior [24]. Furthermore, in our experiments, the trait variables technology commitment, tendency to anthropomorphize, and personality characteristics (Big Five) were not connected to ambivalence towards robots. Future research might investigate other variables from the ambivalence literature, such as need for cognition [33] or a general tendency for ambivalent attitudes [46]. Possibly, ambivalence is not necessarily a negative status to reduce, but also a factor that ameliorates decisions and makes ambivalent individuals less susceptible to cognitive bias [46].

Future research might manipulate ambivalence experimentally by having participants generate arguments for and against the attitude objects themselves, or univalence by having participants generate just one-sided arguments [21]. This way, a stronger manipulation of ambivalence might be achieved and affect behavioral and cognitive indicators of ambivalence.

10 Conclusion

This paper featured a set of four programmatic experiments to investigate ambivalence on the affective, behavioral and cognitive level concerning various robot stimuli using explicit and implicit measures. Results indicated that self-reported attitudes towards robots are indeed ambivalent and partly evoke behavioral expressions of conflict as measured through mouse tracking data.

Through the current work, we demonstrated the applicability of the ABC of Ambivalence to a new field, namely social robotics, while at the same time exploring the limits of the models applicability. For instance, behavioral indicators of ambivalence towards robots seem to depend on the specific type of robot that is being evaluated. Furthermore, we hope to contribute to the advance of measurement methodology in social robotics, by emphasizing the relevance of measuring ambivalence in attitudes towards robots and providing examples on how to do so on an explicit and implicit level.

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