Going Under Dr. Robot’s Knife: The Effects of Robot Anthropomorphism and Mortality Salience on Attitudes Toward Autonomous Robot Surgeons

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**Abstract**

**Objective:** This study sought to experimentally test two potential factors that could affect the consumer acceptance of autonomous robot surgeons: anthropomorphism and mortality salience. The study also investigated the effect of gender and its interaction with anthropomorphism on attitudes toward autonomous robot surgeons.

**Design and Main Outcome Measures:** A between-subjects experiment with a 2 (anthropomorphism: low vs. high) x 2 (mortality salience: no vs. yes) factorial design was conducted (*N*=196). The trust in the autonomous surgical robot and the willingness to undergo autonomous robotic surgery served as the dependent variables.

**Results:** When death thoughts were not active, the human-likeness of the autonomous surgical robot significantly increased the trust in the robot and the willingness to undergo autonomous robotic surgery. Activating death thoughts did not further increase the positive attitudes toward the higher-anthropomorphic robot, while it significantly increased the trust in and the willingness to be operated on by the lower-anthropomorphic robot, rendering both robots comparable. This study also found that women had less positive attitudes toward the autonomous robot surgeon, regardless of the robot’s human-likeness.

**Conclusion:** Anthropomorphism and mortality salience can both positively affect the acceptance of autonomous robotic surgery but only in the absence of one another.

*Keywords:* Anthropomorphism, mortality salience, autonomous robot surgeon, robotic surgery, consumer attitudes

# Introduction

Developments in engineering and programming have enabled the realization of surgical robots that can autonomously perform surgical tasks under the supervision of human surgeons. Today, there are numerous surgical robots in use with varying degrees of autonomy, and many more are expected to be developed in the near future with increasing levels of autonomy (Attanasio et al., 2021; Jamjoom et al., 2020; Thai et al., 2020). However, research on existing surgical robots shows that people are generally uneasy with regard to undergoing robotic procedures (Boys et al., 2016; Buabbas et al., 2020; Milner et al., 2020; Stai et al., 2020; Zineddine & Arafa, 2013). As such, it would not be a surprise to face an even stronger reluctance in public acceptance of more autonomous surgical robots. This study aims to experimentally test two factors, anthropomorphism and mortality salience, that could potentially affect attitudes toward autonomous surgical robots and autonomous robotic surgery.

# A Brief History of Surgical Robots

In 1984, two medical engineers from the Jack Bell Research Centre at Vancouver General Hospital, Dr. James McEwen and Geof Auchinleck, led the development of the world’s first surgical robot, Arthrobot, which could be controlled via voice command and was designed to serve as an assistant to manipulate and position patients’ limbs during orthopedic surgery. Arthrobot was clinically tested in 1985 in an orthopedic surgery conducted by Dr. Brian Day and then used in many operations thereafter (Auchinleck, 2019; Lechky, 1985). Just one month after the first clinical use of the Arthrobot, another team, led by Dr. Yik San Kwoh, clinically tested the first neurosurgical robot, PUMA 200, in a CT-guided brain tumor biopsy (Kwoh et al., 1985, 1988). These first exemplars of robotic surgery inspired the development of various more-developed surgical robots with varying levels of autonomy (for reviews, see Attanasio et al., 2021; Thai et al., 2020; Yip & Das, 2018), and since then surgical robotics became a booming industry that is now estimated will have a market size of $12.6 billion in 2025 (Stewart, 2020). More importantly, the proportional use of robot-assisted procedures within general surgical procedures has increased dramatically in recent years, from 1.8% to 15.1% in 2012 and 2018, respectively (Sheetz et al., 2020).

Existing surgical robots are designed for use on hard tissues or fixed targets. However, recent trials proved that surgical robots could also perform on soft, deformable tissues. For example, Shademan and colleagues (2016) developed an autonomous surgical robot, the Smart Tissue Autonomous Robot (STAR), and tested it on a soft, deformable, and mobile tissue, i.e., pig bowel, both in *ex vivo* and *in vivo* experiments. In a series of *ex vivo* experiments, STAR outperformed experienced human surgeons in several metrics (e.g., leak pressure, suturing mistakes) on surgical tasks involving linear suturing of a longitudinal cut and suturing together the ends of a cut intestine. An *in vivo* experiment also showed promising results, as STAR’s work was comparable to that of an expert human surgeon. Furthermore, the *ex vivo* experiment was conducted mostly autonomously by the robot. The human surgeon's supervisory actions accounted only for 12.9% of the total time (Shademan et al., 2016). Another promising development in autonomous robotic surgery was from China. In 2017, the South China Morning Post reported thatan autonomous dentistry robot installed two dental implants in a patient’s mouth with no human intervention (Yan, 2017). These exemplars are promising in that autonomous surgical robots can be used for any form of tissue with greater efficiency and safety and that surgical robots could be even more autonomous in the near future thanks to the growing accessibility of enabling technology and know-how.

# Attitudes Toward Surgical Robots and Robotic Surgery

As the level of robot autonomy increases, the involvement of human surgeons in the surgical processes decreases. This may reduce complications caused by human error; however, such a decrease in human surgeons’ involvement may also reduce psychological comfort on the part of patients, especially when the procedure requires invasive interventions.

Research on the attitudes toward robotic surgery shows that individuals generally feel uncomfortable with such. A consistent finding in surveys on public perceptions is that most people indicate a preference for traditional methods over robotic surgery (Boys et al., 2016; Buabbas et al., 2020; Milner et al., 2020; Stai et al., 2020; Zineddine & Arafa, 2013). This unwillingness to undergo robotic surgery is probably not driven by unawareness of or a disbelief in the advantages of robotic surgery; rather, it is mostly due to feelings of fear and discomfort (Boys et al., 2016; Buabbas et al., 2020; Stai et al., 2020). When the surgical procedure is invasive, hence more subject to feelings of fear and discomfort, people are less willing to accept robotic surgery (Milner et al., 2020).

Although scarce, research on individual differences in willingness to undergo robotic surgery also documented several predictors of acceptance of robotic surgery. For example, Anania et al. (2020) found that factors such as familiarity with robotic surgery, the perceived value of robotic surgery, and happiness were positively associated with willingness to undergo robotic surgery, whereas factors such as wariness of new technologies, openness, fear of surgery, anger, and fear were negatively associated with the willingness to undergo robotic surgery. Further, they found that females were less willing to undergo robotic surgery than males. This gender difference has also been documented in recent research on automated robotic surgery (Milner et al., 2020; Stai et al., 2020) and research on several other autonomous devices, such as driverless ambulances (Winter et al., 2018), driverless buses (Dong et al., 2019; Salonen, 2018), and autonomous cars (Kyriakidis et al., 2015; Payre et al., 2014). Moreover, a recent qualitative study on the gender difference in attitudes toward robot-assisted surgery has also documented the same difference between male and female interviewees (McDermott et al., 2020). However, it also found a noticeable difference between male and female interviewees with regard to anthropomorphism in their representations of robotic surgery.

# The Role of Anthropomorphism in Human-Robot Interaction

Anthropomorphism refers to the pervasive human tendency to attribute human characteristics to non-human entities. In recent years, anthropomorphism has received a great deal of attention from behavioral researchers in a number of fields, especially marketing and psychology. A large body of research on anthropomorphism in these fields revealed that anthropomorphism can lead to positive attitudes for a vast array of entities, from nature (Liu et al., 2019; Tam et al., 2013) to agricultural products (Koo et al., 2019), from beverages (Aggarwal & McGill, 2007; Chen, 2017) to snacks (Delbaere et al., 2011), and from electronic devices (Zhang & Patrick, 2018) to cars (Aggarwal & McGill, 2007; Chandler & Schwarz, 2010).

More relevant to the current study, numerous studies have found that anthropomorphism increases trust in autonomous devices (de Visser et al., 2016; Lee et al., 2015; Niu et al., 2018; Verberne et al., 2015, Waytz et al., 2014), service robots (Kiesler et al., 2008; Tussyadiah & Park, 2018; van Pinxteren et al., 2019), and, more importantly, surgical robots (McDermott et al., 2020). In their qualitative study, McDermott et al. (2020) observed that some interviewees tended to anthropomorphize the autonomous surgical robots and that those who anthropomorphized the robot were less frightened by the concept of robotic surgery. Therefore, in the present study, we anticipated that anthropomorphism would increase the trust in the autonomous surgical robot and the willingness to undergo autonomous robotic surgery.

*H1: Participants will have (a) greater trust in the autonomous surgical robot, and (b) greater willingness to undergo autonomous robotic surgery when the robot is higher (vs. lower) in anthropomorphism.*

Based on the findings regarding the gender difference in attitudes toward robotic surgery, we anticipated that females would have more negative attitudes than males. However, McDermott et al. (2020) further found that females and males also differed in their representations of the robotic surgery process. Specifically, they found that males tended to anthropomorphize the surgical robots and described the robotic surgery process in anthropomorphic terms, whereas females deemed robotic surgery to be dehumanizing. They discussed the idea that this gender difference in anthropomorphic tendency might be the underlying reason for the gender difference in attitudes toward robotic surgery. If this is the case, in the present study we would expect the gender difference to be more pronounced in the evaluation of the lower-anthropomorphic surgical robot since the higher-anthropomorphic robot should readily be anthropomorphized, regardless of the participant gender, thanks to the innate human predisposition to search for and detect faces (Aggarwal & McGill, 2007; Crouzet et al., 2010; Johnson et al., 1991; Martin et al., 2018).

*H2: Females will have (a) lower trust in the autonomous surgical robot, and (b) lower willingness to undergo autonomous robotic surgery than males.*

*H3: The gender difference in (a) trust in the autonomous surgical robot and (b) willingness to undergo autonomous robotic surgery will be more pronounced when the robot is lower (vs. higher) in anthropomorphism.*

# Mortality Salience in Patient Surgical Decision Making

Mortality salience refers to one’s conscious awareness of their own mortality. As most surgical interventions involve mortality risks, patient surgical decisions engender death thoughts. In other words, patients make surgical decisions under mortality salience the majority of the time. However, studies investigating risky, health-related decisions neglect the mortality salience component of such decisions and fall short of capturing the patient perspective.

According to the Construal Level Theory (Trope, Liberman, & Wakslak, 2007), there is a bidirectional relationship between psychological distance and mental construal. The theory predicts that the psychologically closer the entity (a situation, event, person, object, idea, etc.) is to the individual, the more concrete will be the construal of that entity in the mind of the individual, and vice versa (Trope & Liberman, 2010). Moreover, the theory and evidence suggest that the level of construal affects the evaluations and behaviors with respect to the phenomenon of interest (Soderberg et al., 2015).

Research shows that a concrete construal of threats motivates engagement with actions directed to reduce the threat (Carmi & Kimhi, 2015; Chandran & Menon, 2004; Maiella et al., 2020; Nandakumar et al., 2017; Shin et al. 2020). From this perspective, the mortality threat should increase the sense of psychological closeness to the surgical process due to its relevance therein. This, in turn, should result in a concrete construal of the situation and motivate behaviors that have the potential to reduce the threat. Therefore, we argue that evaluating a surgical robot and making a surgical decision under mortality salience will lead to greater trust in the surgical robot and an increased willingness to undergo autonomous robotic surgery, as autonomous robotic surgery was framed as more efficient and less risky than human-led surgery.

*H4: Participants in the mortality salience condition will have (a) higher trust for the autonomous surgical robot, and (b) higher willingness to undergo autonomous robotic surgery than the participants in the control conditions.*

As for the interaction between anthropomorphism and mortality salience, there is no relevant empirical evidence to draw upon. In the absence of evidence to inform our hypotheses, we opted to examine the potential interaction of anthropomorphism and mortality salience exploratorily.

# Present Study

The objective of the present study is to investigate the effects of the human-likeness of the autonomous surgical robot and death thoughts on the trust in the robot and willingness to undergo autonomous robotic surgery. It also investigates the effect of gender and its interaction with anthropomorphism on attitudes toward autonomous robot surgeons. The study procedure was approved by the Social and Humanities Ethics Committee of Sakarya University. Informed consent was obtained from each participant. At the end of the experiment, participants were offered free psychological support from a prearranged psychologist if so required; however, none of the subjects expressed or showed any interest in this offer.

## Method

This study is a 2 (anthropomorphism: low vs. high) x 2 (mortality salience: no vs. yes) between-subjects design experimental study where the trust in the autonomous surgical robot and the willingness to undergo autonomous robotic surgery serve as the dependent variables.

### Participants

Participants were business faculty students who were at least 18 years old and had enrolled in several business courses. They were invited to participate in the study via an invitation letter posted to their student information systems, wherein they were told that the study would investigate college students’ general attitudes, and they were provided with a link to the associated survey on Qualtrics™. Participation was voluntary and was not compensated either monetarily or by course credits. A total of 271 students participated in the study. Of these, 49 dropped out before the measurement of the dependent variables, four were foreign students, 11 failed the attention check, and 11 did not appropriately respond to the reverse items. These cases were excluded from the analysis, leaving a final sample of 196 (70.9% females; *M*age = 21.33, *SD* = 2.23), which affords ~99% power to detect a medium-sized effect (ηp2= 0.06) in a 2 x 2 between-subjects factorial MANOVA (Faul et al., 2007).

### Materials

***Mortality Salience Manipulation:*** Death thoughts were manipulated via a text about COVID-19 and an open-ended question from the classic mortality salience manipulation. Participants in the mortality salience condition first read a short text about the deadliness of COVID-19, human vulnerability to it, and the inevitability of death reminders during the pandemic. The text ended with a closed-ended question that asked whether they thought about death/mortality during these times. This question was intended to prepare participants for the following open-ended question that asks about the feelings and thoughts that thinking about death evokes. The text, the closed-ended question, and the open-ended question read as follows:

*The Coronavirus (COVID-19) pandemic, which to date has caused hundreds of thousands of people to die, continues to kill tens of thousands of people every day. As creatures vulnerable to this unexpected threat, we follow the statistics shared by officials every day, constantly encounter content that reminds us of death and mortality in social media and other media outlets, and possibly know of deaths within our social circle. Do you ever find yourself contemplating death nowadays?*

*1- Never 2- Seldom 3- Sometimes 4- Often 5- Always*

*How exactly do you feel when you remember that you will die one day, and what do you think? Please write down, as specifically as you can, the thoughts and emotions that thinking about your own death arouse in you.*

Participants in the control condition went through a parallel process but substituted with a neutral topic on the world film industry and film awards. The wording was comparable to the text and the questions in the MS condition. The text, the closed-ended question, and the open-ended question read as follows:

*The world film industry, which to date has presented hundreds of thousands of movies and series to audiences, continues to produce tens of thousands of new movies and series every year. As consumers who have to choose among the alternatives, we follow the content shared by the producers, conduct research about movies and series on social media and other media outlets, or we get movie or series recommendations from our social circle. Do you ever research the awards that the movies or series you’ll watch have received?*

*1- Never 2- Seldom 3- Sometimes 4- Often 5- Always*

*When you find out that a movie or a series has received a significant award, what do you think about that movie or series? Please write down, as specifically as you can, the feelings and thoughts that noticing that the film has received an award arouse in you.*

***Anthropomorphism Manipulation:*** Anthropomorphism was manipulated by means of visual and verbal cues. Participants were presented with a realistic 3D image of a surgery robot and a description of it. In the AM condition, the robot was named "DR. MX" and described in an agentic way (surgeon robot), and there were two light buttons on its upper head-like part intended to mimic a face when coupled with the small display kit on the same part. In the non-AM condition, the robot had rather a technical name (DRMX) and was described as a machine (surgery robot) by using phrases nearly identical to those in the AM condition, and the number of light buttons was increased to three to take away the eye-like view (see Figure 1). The descriptions of robots are as follows:

*DR. MX (DRMX) is a fully autonomous surgeon (surgery) robot, a product of artificial intelligence technology. By using machine learning, it has been trained (developed) to perform an entire surgical process without any human support.* *Thanks to its magnetic scanning feature and highly sensitive sensors, DR. MX (DRMX) accurately determines the points to be operated and performs actions such as incision and stitches almost flawlessly.* *Therefore, the recovery time is shorter, and the risk is much lower in operations performed by (with) DR. MX (DRMX). In the tests carried out by three independent organizations, it was determined that the error rate in operations performed by (with) DR. MX (DRMX) was approximately four times lower, and the recovery time was shortened by half compared to the operations performed by human surgeons.* *DR. MX (DRMX), which has operated (been used) only on animals so far, is planned to be ready to perform (be used) on humans in 2022. Please answer the following statements after reviewing the DR. MX (DRMX).*

***Dependent Measures:*** As dependent variables, trust in the autonomous surgical robot and willingness to undergo autonomous robotic surgery (WTU) was measured. Trust was measured via two generic items: (1) *DR. MX (DRMX) looks trustworthy,* and (2) *DR. MX (DRMX) looks dependable*.These two items were collapsed into a mean score for trustworthiness (*r* = .89). WTU was measured with four items; two were concerned with a relatively lower-risk operation (arm fracture surgery), while the other two were concerned with a relatively higher-risk operation (heart surgery): (1) *If my arm were broken and I needed surgery, and my doctor had recommended that the DR. MX (DRMX) do this, I would have accepted.* (2) *Even though the DR. MX (DRMX) has a much lower error rate, I would have liked a human surgeon to do my arm surgery (R).* (3) *If I had to have heart surgery and my doctor had recommended that the DR. MX (DRMX) do it, I would have accepted.* (4) *Although the DR. MX (DRMX) has a much lower error rate, I would have liked a human surgeon to do my heart surgery (R).* After appropriately recoding the reverse items, these four items were averaged into a composite score for willingness to undergo autonomous robotic surgery (Cronbach’s *α* = .91). The response scale for both measures ranged from 1 (*strongly disagree*) to 7 (*strongly agree*).

***Delay and Distraction:*** According to the Terror Management Theory, death thoughts become more accessible, and therefore more effective on defensive behaviors after removed from focal attention to the fringes of consciousness (Greenberg et al., 1994; Pyszczynski et al., 2005). For this reason, most research studies employ a delay period or include distracting tasks following the mortality salience manipulation to help participants suppress conscious death thoughts before measuring the dependent variable of interest. In the present study, two unrelated tasks were employed following the mortality salience manipulation, a single-item life evaluation measurement and a consumer product evaluation task that involved eight Likert-type items. These two tasks served as task-switching activities to divert MS participants' attention away from death thoughts before measuring the dependent variables.

***Attention Check:*** A seven-point question was employed both to check for attentiveness and to identify foreign students. Participants were asked to tick “6” if foreign students, but not to make a tick if otherwise. Those who ticked “6” were identified as foreign students, and those who ticked any other option were identified as inattentive.

### Procedure

Data was collected between May 23 and June 12, 2020, via Qualtrics™. Data for the experiment were collected as part of a battery of measures for unrelated studies. Upon clicking the survey link in the invitation letter, participants were initially shown the informed consent form, and those who accepted it proceeded to the survey. In the survey, participants first indicated their age and gender and proceeded to the following pages to respond to measures for unrelated studies. They were then randomly assigned to either the MS or the control condition and were presented with the respective texts and questions. Following the manipulation, they responded to a single-item measure, the attention check question, and eight items for evaluating a consumer product, which provided the delay and distraction necessary for observing the unconscious effects of death thoughts. They were then randomly assigned to either the low-anthropomorphism or the high-anthropomorphism condition and were presented with the images and descriptions of the respective surgical robots. Finally, they responded to the dependent measures, trust in the robot and willingness to undergo autonomous robotic surgery, and were then thanked and debriefed.

## Results

### Manipulation Check

As a manipulation check for the mortality salience manipulation, the content of the responses given to the open-ended experimental questions was screened. The death-relevance of MS participants’ responses would suggest that they engaged in death-related thoughts. Similarly, the death-irrelevance of control participants’ responses would suggest that they were free from such thoughts. After excluding participants who were not eligible for the analyses, responses given to the open-ended manipulation question were screened in terms of their relevance to death. This examination revealed that all participants in the MS condition provided death-relevant answers, whereas none of the control participants provided such. Note that in another study with participants from the same pool and conducted around the same time as the present study, we employed this exact manipulation along with a death-thought accessibility task placed at the end of the study and obtained satisfactory results on the manipulation’s effect on the accessibility of death thoughts (*d* = .50, *p* = .002; Sonmez, 2022).

As for the anthropomorphism manipulation, we conducted a pre-test with 58 participants to determine whether the higher-anthropomorphic robot was perceived as more humanlike than the lower-anthropomorphic robot. Participants were randomly assigned to either the low anthropomorphism or the high anthropomorphism condition and evaluated the respective robots with seven Likert-type items on a seven-point scale ranging from 1 (*completely disagree*) to 7 (*completely agree*). Two of the items measured the perceived human-likeness of the robots (looks like a human, feels like a human). The five further items were on mental state attribution and measured the extent to which participants thought the robot appeared to have “a mind of its own”, “intentions” “free will”, “consciousness”, and “the ability to experience emotions” (Epley et al. 2008). It was found that the human-likeness ratings were statistically significantly higher for the higher-anthropomorphic robot, *t*(56) = 2.125, *p* = .038, *d* = .57. These results support the effectiveness of the manipulation on the perceived human-likeness of the robots. Mental state attribution, on the other hand, was also higher for the higher-anthropomorphic robot, however, the effect did not reach the conventional level of statistical significance (*p* = .15, *d* = .39), most likely due to low statistical power and/or the equality in robot complexity. Using this same measure, Hart et al. (2013) found that the magnitude of mental state attribution was related to product complexity and that the products with the same level of complexity did not differ on this measure. Therefore, the equality of both robot surgeons’ complexities may have reduced the difference in mental state attribution. Another reason could be the measurement error. Measuring mental state attribution via five generic items may have reduced the measurement accuracy and led to the failure to capture the difference (see Manzi et al., 2020 for a more comprehensive measure of mental state attribution). However, both the direction and the magnitude of the effect and the significant difference in perceived human-likeness suggest the success of the anthropomorphism manipulation.

### Tests of Hypotheses

In order to control for the inflation of Type-I errors resulting from multiple testing, we preferred to run a two-way multivariate analysis of variance (MANOVA) instead of running separate two-way analyses of variance (ANOVA) for each dependent variable. To examine the effects of anthropomorphism (H1), mortality salience (H4), and their interaction on the combined dependent variables, a two-way MANOVA was conducted. Multivariate test results revealed a non-significant main effect of anthropomorphism (*p* = .092) and a non-significant main effect of mortality salience (*p* = .35). However, the interaction of anthropomorphism and mortality salience had a statistically significant effect on the combined dependent variables, *F*(2, 191) = 3.702, *p* = .026, Wilks’ Λ = .963, ηp2= .037. This effect was significant both in the trust (ηp2= .034, *p* = .01) and in the WTU scores (ηp2= .026, *p* = .023).

To decompose the nature of the interaction, simple main effects on the combined dependent variables were compared. This analysis revealed that, when mortality was not salient, participants had statistically significant higher trust in (ηp2= .041, *p* = .005) and willingness to be operated on by (ηp2= .048, *p* = .002) the higher-anthropomorphic robot than the lower-anthropomorphic robot, *F*(2, 191) = 5.404, *p* = .005, Wilks’ Λ = .946, ηp2 = .054. However, when mortality was salient, there was no significant difference between the higher-anthropomorphic and the lower-anthropomorphic robots (*p* = .60). Examining the other pair of simple main effects revealed that mortality salience did not significantly affect the trust in or the willingness to be operated on by the anthropomorphic robot (*p* = .47). However, it increased the trust in (ηp2= .032, *p* = .013) and willingness to be operated on by (ηp2= .036, *p* = .008) the lower-anthropomorphic robot to a significantly higher level than in the control condition, *F*(2, 191) = 4.084, *p* = .018, Wilks’ Λ = .959, ηp2 = .041, which then led to comparable levels of trust and WTU scores for both robots when under mortality salience (see figures 2 and 3). These results lent conditional support for H1 and H4, such that both anthropomorphism and mortality salience had significant positive effects on attitudes toward autonomous robotic surgery but only in the absence of one another.

We also exploratorily investigated whether the trust in the robot mediated the effect of anthropomorphism on willingness to undergo autonomous robotic surgery when mortality was not salient using the PROCESS Macro Model 8 (Hayes, 2017). Results suggested the mediating role of trust. The index of the moderated mediation was significant (*β* = -.76, *SE* = .30, CI = [-1.38, -1.19]) and the indirect effect of anthropomorphism on willingness to undergo autonomous robotic surgery was significant when mortality was not salient (*β* = .60, bootstrap 95% CI = [.14, 1.1]). However, note that examining mediation effects with cross-sectional data is criticized for producing substantially biased estimates of parameters (Fairchild & McDaniel, 2017; Maxwell & Cole, 2007).

To examine the main effect of gender (H2) and the effect of its interaction with anthropomorphism (H3), a two-way MANOVA was conducted. Results revealed only a significant main effect of gender on the combined dependent variables, such that females showed lower trust in the robot surgeon (ηp2= .014, *p* = .097) and lower willingness to undergo autonomous robotic surgery (ηp2= .044, *p* = .003) than males, *F*(2, 191) = 4.419, *p* = .013, Wilks’ Λ = .956, ηp2 = .044. The gender-anthropomorphism interaction was not significant (*p* = .96). These results supported H2 but not H3. Note that we repeated the same analyses a hundred times after balancing for the gender by randomly selecting an equal number of female participants to males and obtained the same pattern of results in more than three-quarters of these reproductions.

Finally, we explored the two-way interaction between gender and mortality salience, and the three-way interaction between gender, mortality salience, and anthropomorphism. However, neither of these effects were significant (*p* = .78 and *p* = .82, respectively).

# Discussion and Conclusion

***Theoretical Implications***

We found that the attitudes toward autonomous surgical robots and autonomous robotic surgery are generally negative at baseline and that anthropomorphism and mortality salience can respectively enhance positive attitudes. Specifically, we found that when death was not reminded, the human-likeness of the autonomous surgical robot positively affected the trust in the robot and the willingness to undergo autonomous robotic surgery. However, once death was reminded, anthropomorphism no longer remained an important factor in terms of trust in the robot and willingness to undergo autonomous robotic surgery. Under mortality salience, the trust in the robot and willingness to undergo autonomous robotic surgery was significantly higher than the baseline (low anthropomorphism, no mortality salience) regardless of the human-likeness of the robot. Perhaps, when death thoughts were accessible in mind, the robot’s human-likeness became a trivial factor, and the evaluation and decision were driven rather by rational considerations such as the lower risk and higher efficacy in autonomous robotic surgery.

These findings emphasize the importance of ecological factors in behavioral research and how they can alter the results. Mortality salience may be a negligible factor for low-risk health-related decisions. However, it is an inevitable component of high-risk health-related decisions, and therefore, should be taken into consideration by researchers when examining such attitudes and behaviors. For example, if the current study had concerned the effect of anthropomorphism on attitudes toward a well-known, already-in-use tool and ignored the role of mortality salience therein, we might have concluded that incorporating anthropomorphism into the design or communication of the tool could increase positive attitudes. However, under ecologically more valid conditions, this effect might have been overridden by other relevant factors, such as mortality salience. Having said that, the current study concerned a product that has not been fully realized and that people are not aware of yet. Therefore, there are important implications regarding the role of anthropomorphism in developing positive attitudes toward these devices (discussed below).

This study also found that gender had a significant main effect on attitudes toward autonomous robotic surgery. Consistent with prior research, females had more negative attitudes toward autonomous robotic surgery than males. However, contrary to the contention of McDermott et al. (2020) and our hypothesizing, the main effect of gender did not depend on robot anthropomorphism. Therefore, anthropomorphism may not be the underlying reason for the gender difference in attitudes toward robotic surgery. One alternative factor that could explain the gender difference could be the associated risk perception. A large body of research suggests that females perceive risks to be higher than do males in general (Byrnes et al., 1999; Harris et al., 2006; Hitchcock, 2001), an effect which is also evident in the health domain (Kim et al., 2018; Morioka, 2015; Tandi et al., 2018). Moreover, research shows that, regardless of the procedure, females experience higher preoperative anxiety than males (Jawaid et al., 2007; Mitchell, 2012). Therefore, the gender difference in attitudes toward robotic surgery may not be unique to robotic surgery; rather, it may be a reflection of the apparently inherent gender-based characteristic in risk perception.

***Managerial Implications***

The findings of this study speak to a situation where individuals do not have available attitudes toward autonomous surgical robots, as these robots are not fully realized and publicized as yet. Once these robots are publicized, individuals will form attitudes about them that will later influence their evaluations and decisions regarding autonomous robotic surgery when a surgical operation is required for them or their close others. Attitudes are hard to change; negative attitudes may be even harder to change (Bodenhausen & Gawronski, 2013; Lutz, 1975). Once strong negative attitudes about these robots are formed, the natural or induced mortality salience before or at the time of the decision may not be as effective in increasing patients’ trust and willingness in the same manner as in this study. Thus, negative initial attitudes could well impede the adoption of autonomous robotic surgery. Therefore, we believe that producers, communicators, and employers of robot surgeons should prioritize enabling the formation of positive initial attitudes among people, provided that the employment of these robots offers more value than the traditional methods.

Positive attitudes toward autonomous surgical robots can lead to confidence and comfort for patients when a surgical operation with these robots is required, which may reduce pre-surgical anxiety, and, in turn, translate into more positive intra-operative and post-operative outcomes (Ali et al., 2014; Kil et al., 2012; Kim et al., 2010; Osborn & Sandler, 2004). Positive attitudes can also lead to confidence and comfort for patients’ close others, who can reduce the decisional conflict patients experience during surgical decision-making (Rini et al., 2011). Accordingly, a likely positive outcome can result in satisfaction and higher positive word-of-mouth behaviors by patients and their immediate circle, which can further enhance the pace of adoption of these technologies.

Given the positive effect of anthropomorphism when mortality was not salient, we believe that the public’s first encounters with autonomous surgical robots should include anthropomorphic elements since these encounters are most likely to be under circumstances of little or no mortality salience (e.g. product launch events, publicity campaigns, news on social and traditional media, interpersonal communication). Communicating and publicizing these robots in an anthropomorphic way may help individuals develop positive attitudes and thus more readily adopt autonomous robotic surgery. Also, research shows that while some consumers could be fascinated merely by a robot’s technical properties and functional performance, some still expect a degree of human-likeness (Manzi, Massaro et al., 2021; Manzi, Sorgente et al., 2021). Incorporating anthropomorphism in the design or communication of the autonomous robot surgeons could help meet these consumer expectations and further facilitate the adoption of these robots.

***Limitations and Future Research***

The current study has several limitations that may have implications for future research directions. The study sample consists of business faculty students, which may not be representative of the general population, and the study was conducted online. Future research could attempt to replicate the current study with a patient sample and in an ecologically more realistic context. Another limitation of the present study is that it used only one robot and employed anthropomorphism both in the design and description of the robot. Future research could investigate the effects reported here using different robots with varying levels and types of anthropomorphism (e.g., visual, verbal). Furthermore, the robot was framed as completely autonomous in the present study. Future research could compare fully autonomous robotic surgery to human-supervised autonomous robotic surgery in order to examine whether human involvement could affect the results. Last but not least, future research could conduct direct or conceptual replications of the current study to establish the findings’ robustness and reliability and investigate potential cognitive mechanisms underlying the reported effects.

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**Data and Code Availability:** The data that support the findings of this study and the SPSS syntax to reproduce the main results are openly available at https://osf.io/mweju.

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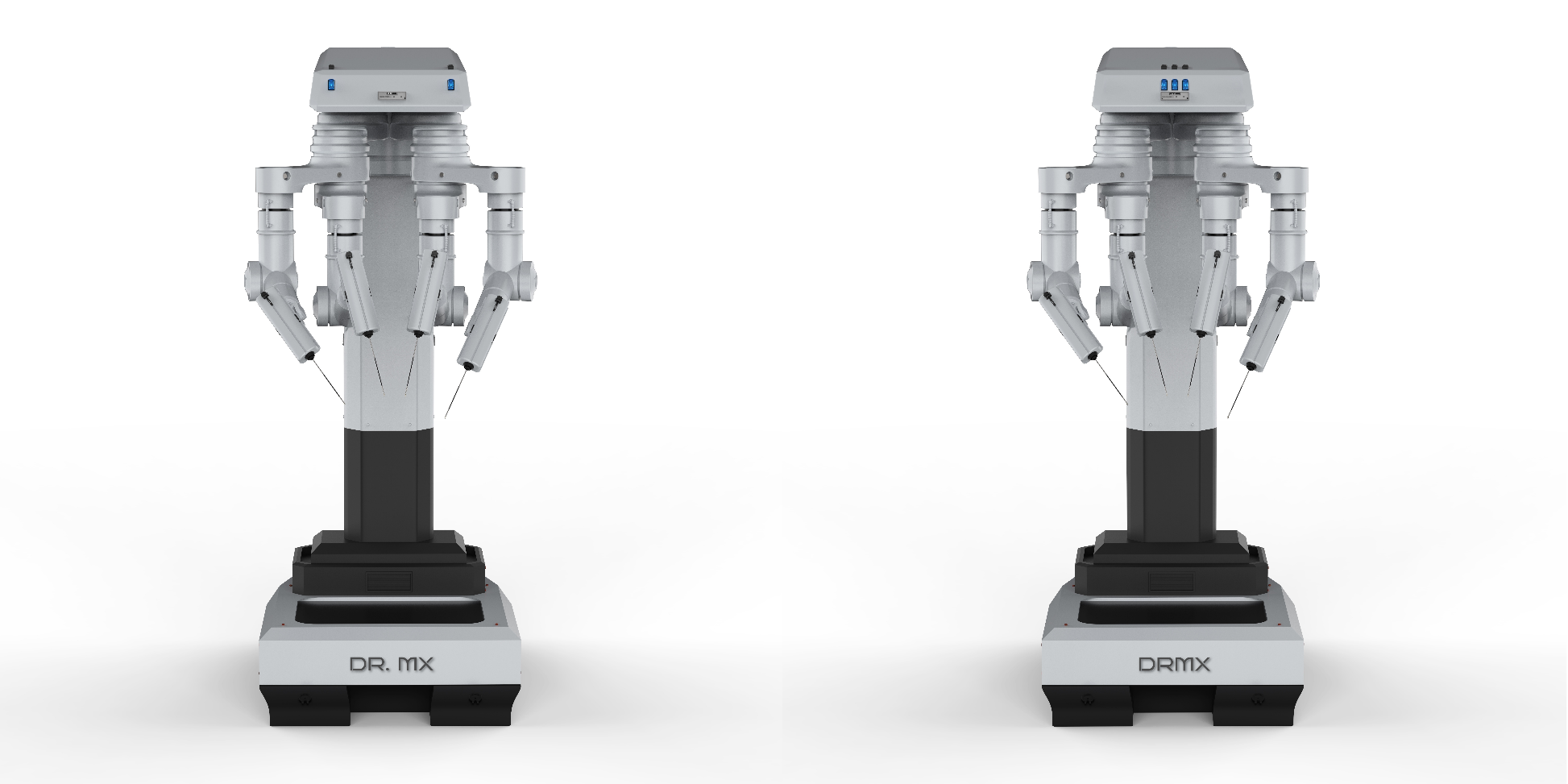
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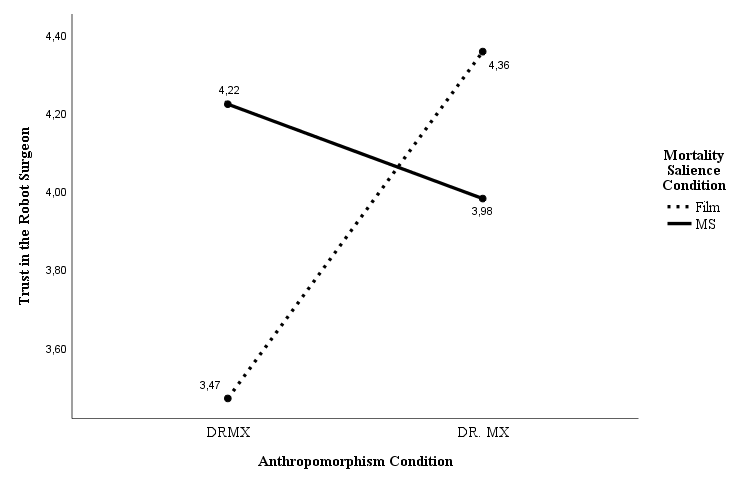
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# Figures

**Figure 1.** The higher-anthropomorphic and the lower-anthropomorphic robot surgeons



**Figure 2.** Estimated Marginal Means of Trust in the Robot Surgeon as a Function of Mortality Salience and Robot Anthropomorphism



**Figure 3.** Estimated Marginal Means of Willingness to Undergo Autonomous Robotic Surgery (WTU) as a Function of Mortality Salience and Robot Anthropomorphism

