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Postprint

This is the accepted version of a chapter published in *Social Robots: Technological, Societal and Ethical Aspects of Human-Robot Interaction*.

Citation for the original published chapter:

Akalin, N., Kristoffersson, A., Loutfi, A. (2019)

Evaluating the Sense of Safety and Security in Human - Robot Interaction with Older People

In: Oliver Korn (ed.), *Social Robots: Technological, Societal and Ethical Aspects of Human-Robot Interaction* (pp. 237-264). Springer

Human-Computer Interaction Series

https://doi.org/10.1007/978-3-030-17107-0_12

N.B. When citing this work, cite the original published chapter.

Permanent link to this version:

<http://urn.kb.se/resolve?urn=urn:nbn:se:oru:diva-78493>

Evaluating the Sense of Safety and Security in Human-Robot Interaction with Older People

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Abstract For many applications where interaction between robots and older people takes place, safety and security are key dimensions to consider. ‘Safety’ refers to a perceived threat of physical harm, whereas ‘security’ is a broad term which refers to many aspects related to health, well-being and aging. This chapter presents a quantitative evaluation tool of the sense of safety and security for robots in elder care. By investigating the literature on measurement of safety and security in human-robot interaction, we propose new evaluation tools specially tailored to assess interaction between robots and older people.

Key words: sense of safety and security, quantitative evaluation tool, social robots, elder care.

1 Introduction

The focus of social robotics research is on designing, developing and evaluating robots that interact with humans in social environments. The rapid growth of the aging population in Europe (European Commission, 2014) and worldwide attracts researchers’ attention as they work to develop assistive technologies for improving elder care. In the effort to support older people in their domestic environments, to preserve their independence and to relieve the burden of caregivers, social robots have great potential. Many studies have examined the usage of robots in elder care settings (Bedaf et al., 2015), including design issues (Broadbent et al., 2011; Wu et al., 2012), acceptance (De Graaf & Allouch, 2013; Heerink et al., 2010), older people’s experience and their attitudes toward robots (Vandemeulebroucke et al., 2018). For example, Fischinger et al. (2016) found that older people (aged over 70)

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had a positive reaction to the socially assistive care robot developed in the Hobbit project in terms of perceived usability, acceptance and affordability.

To use social robots in homes and care facilities, understanding the underlying reasons for the acceptance or rejection of this technology is crucial. The acceptance of social robots among older people includes several dimensions and the one studied in this chapter focuses on how social robots impact ‘sense of safety and security’. In human-robot interaction (HRI) literature, we see a variety of terms being used that relate to the sense of safety and security. These include perceived safety (Bartneck et al., 2009), psychological safety (Lasota et al., 2014) and mental safety (Nonaka et al., 2004). However, a broader term, ‘sense of safety and security’ (Fonad et al., 2006), is used in gerontology literature.

For effective HRI, understanding the target user and designing the interaction based on the user needs are key challenges. In this chapter, we exclusively focus on older people’s sense of safety and security in the context of using social robots in elder care. Boström et al. (2013) pointed out that *secure relationships, sense of control, and perceived health were significantly related to the subjects’ sense of security.*, p. 1. The sense of security differs depending on context but is not only affected by access to an emergency response alarm system. Rather, the sense of security is more associated with the existence or establishment of secure relationships. Thus, the social robots’ ability to foster secure relationships with the older people is an important aspect of effective HRI. The main challenge is understanding the underlying factors affecting an older person’s sense of safety and security, and how to model these factors for better HRI. Addressing this challenge requires the consultation of gerontology studies. With the intention of narrowing the gap between the terminology used in HRI and gerontology literature, this chapter presents the notion of *the sense of safety and security for HRI*, and introduces an approach for measuring it based on developed tools and evaluations in two user studies.

In the remainder of this chapter, the sense of safety and security is explained, with its components, in Section 2. The tool developed was tested in a video-based study which is described in Section 3. A revised version of the tool that was tested with older people is presented in Section 4. Section 5 presents our proposed initial model of sense of safety and security. The chapter concludes in Section 6 by summarizing the open problems and future directions. This chapter is an extended version of the paper presented at the International Conference on Social Robotics (ICSR) 2017 (Akalin et al., 2017) in which the initial results of the video-based study were published.

2 The Sense of Safety and Security

In order to measure the sense of safety security in older person-robot interaction, it is important to clearly define the term ‘sense of safety and security’. In this section, we first provide definitions of safety and security in general in Section 2.1. Thereafter, we discuss outcomes of gerontology research on older people’s sense of safety and

security in Section 2.2. The various terms relating to safety and security in HRI literature are discussed in Section 2.3.

2.1 Conceptual Definitions of Sense of Safety and Security

The terms ‘safety’ and ‘security’ have extensive usage in different senses and contexts (Boholm et al., 2016; Burns et al., 1992). Therefore, it is difficult to define and generalize these concepts. They have many similarities; both are associated with harm (Burns et al., 1992) and often they are used as synonyms (Boholm et al., 2016). Although both terms deal with risks (Eames & Moffett, 1999), the origin of risk creates the difference between them. Safety refers to hazards that the system may cause and how the system can harm its environment. Security refers to the threats from the system’s environment that can negatively affect the system (Kornecki & Liu, 2013). Another approach to differentiating between safety and security is the intentionality of the harm, i.e., safety refers to unintentional harm (e.g., accidents, occupational injuries, and food poisoning) and security refers to intentional harm (e.g., military occupation and computer viruses) Boholm et al. (2016).

The term ‘safety’ has one subjective and one objective dimension. The subjective dimension includes physical, social, and psychological aspects. The objective dimension is assessed by behavioral and environmental parameters (Maurice et al., 1998). The dimensions can affect each other positively or negatively. In a report by the World Health Organization (Maurice et al., 1998), ‘safety’ is defined as *a state in which hazards and conditions leading to physical, psychological or material harm are controlled in order to preserve the health and well-being of individuals and the community.*, p. 6. Another study (Torstensson Levander, 2007) discusses the social phenomena of safety, security and risk, where the definition of security is given as having no fear.

2.2 Older People’s Sense of Safety and Security

In terms of human perceptions and feelings, the concepts of safety and security are quite difficult to understand and measure. Safety is an essential property of daily life. The importance of safety, including security, was stated in Maslow’s Needs Theory as being one of the fundamental needs of human beings (Maslow, 1943).

It is troublesome to find a general definition for ‘sense of security’ since there is no general consensus about the definition of ‘security’. Other difficulties are the translation between different languages, and finding studies that focus on how to promote a sense of security rather than relating it to different risk perspectives (Boström et al., 2013). Older people’s quality of life and well-being is related to their sense of safety and security (Boström et al., 2013; Fonad et al., 2006). Security is a multidimensional concept that is associated with safety, confidence and trust. One of

the dimensions of security includes interaction within the surrounding environment where the sense of knowledge and control (having knowledge about what is required to cope with and manage situations) are the elements of this interaction (Boström et al., 2013). Petersson & Blomqvist (2011) explored the Swedish concept 'trygghet' by using the story dialog method which involves telling case stories from everyday life to solve problems or reflect on an incident. Their results showed that older people's sense of security is affected by external factors such as being part of a community, having trust in others, being familiar with things and situations, and using various kinds of aids. It is separated into internal (e.g., feeling or state) and external (e.g., safe environment) 'trygghet'. The authors also noted that knowing that it is possible to get in contact with someone by using the phone or an alarm enhances older people's sense of security. There is a close connection between trust and sense of security.

Another study explored the factors that are related to sense of security among older people who were receiving care in nursing homes in Sweden (Boström et al., 2013). The paper stated that sense of security is related to sense of control, secure relationships and perceived health. For older people, having control over service routines is important. In the study, Boström et al. (2013) confirmed that there is a correlation between sense of security and sense of control and knowledge. The factors promoting sense of security for older people are the sense of control, knowledge and having good social relationships. One of the factors negatively affecting the sense of security is living alone. The sense of security highly depends on the personality of the individual, every older person can perceive it differently. Boström et al. (2016) reported a case study with in-depth interviews and observations to understand the sense of security of older people when moving into and living in a nursing home. Based on their findings, the factors that positively affect the sense of security for older people are: having secure relationships with health care service staff, having control over daily routines, and being informed about them. A perceived lack of influence over the daily life and lack of information about routines are associated with a lower sense of security.

Many older people prefer to live in their own home and to continue with their familiar habits which can help them feel more secure (Fonad et al., 2006). In their study, Fonad et al. (2006) investigated the sense of safety and security of older people after moving to a retirement home. They reported that important factors for feeling safe and secure were: continuation of daily routines, familiar habits and practices, and having trust in staff.

2.3 Sense of Safety and Security in HRI

There are a considerable number of contributions dealing with the physical safety of robots in the literature (Bicchi et al., 2008; Haddadin et al., 2010; Wyrobek et al., 2008). Nevertheless, there is only a small amount of research in HRI that considers the sense of safety. The terms that convey a similar meaning as sense of safety are

‘perceived safety’ (Bartneck et al., 2009), ‘psychological safety’ (Kamide et al., 2012; Lasota et al., 2014, 2017) and ‘mental safety’ (Nonaka et al., 2004). In 2009, Bartneck et al. proposed a series of questionnaires to measure the key concepts in HRI, including perceived safety. They defined ‘perceived safety’ as follows: *Perceived safety describes the user’s perception of the level of danger when interacting with a robot, and the user’s level of comfort during the interaction*, p. 76. Their Godspeed V: Perceived safety questionnaire is commonly used in different HRI scenarios. For example, Lichtenthäler et al. (2012) used the Godspeed V questionnaire to compare two different navigation algorithms to investigate the effect of legibility on the perceived safety in a path crossing scenario.

In Lasota et al. (2017), the authors presented a survey of methods for providing safety during HRI. In their survey, they categorized the studies in literature as: safety through control, motion planning, prediction, and consideration of psychological factors of which the last category is our focus of interest. They associated psychological safety with robot attributes including the robot’s motion, appearance, embodiment, gaze, speech, posture, and social conduct. In another paper, Lasota et al. (2014) defined ‘psychological safety’ as: *Ensuring that human-robot interaction does not cause excessive stress and discomfort for extended periods of time*, p. 339. Kamide et al. (2012) also used the term psychological safety and presented a new scale for measuring safety quantitatively. They showed movies of 11 humanoids and asked the participants open-ended questions about safety. Kamide et al. (2012) categorized and analyzed the results and came up with six factors for measuring the psychological safety of humanoids. The factors were as follows: performance, acceptance, harmlessness, toughness, humanness and agency, where the former four factors are more important than the latter two.

Nonaka et al. (2004) defined the term ‘mental safety’ as *humans do not feel fear of or surprised at robots* and physical safety as *robots do not injure humans*, p. 2770, when evaluating the sense of security. They conducted experiments using virtual robots of varying shape, size and motions. While the emotions fear and surprise are related to sense of security, disgust and unpleasantness are related to comfort (Nonaka et al., 2004). Through questionnaires evaluating surprise, fear, disgust and unpleasantness, they observed that robots’ human-like behaviors made the humans feel more comfortable. Weiss & Bartneck (2015) presented a meta-analysis of the usage of the Godspeed Questionnaire Series in HRI research which covers studies reported upon between 2009 and October 2014. They reported that the perceived safety questionnaire had been used in 37 different studies. Another study using the term ‘sense of security’ is Zhang et al. (2016) which proposes a fall detection application for older people by using the Nao robot. The authors claim that the application will increase the sense of security of older people but they do not give a definition thereof.

Although these studies give valuable insights, the *sense of safety and security* has not been fully addressed in HRI research yet. We believe that the sense of safety and security is a key requirement for HRI and should be addressed in a deeper sense including all its aspects and implications for using robots in elder care. In this research, we attempt to identify the factors influencing the sense of safety and security

in HRI, especially for older person - robot interaction. For effective HRI, fostering secure relationships between older people and social robots is crucial. To address this, besides consulting the gerontology literature, we conducted two user studies. We aim not only to advance the state of the art with respect to the understanding of acceptance of social robots, but also to provide insights for robot designers.

3 Designing a Tool for Evaluating Sense of Safety and Security in Social HRI: A Video-based Study

In this section, we describe the first steps in the design of a tool for evaluating the sense of safety and security in social HRI. In order to have control over the scenario in which the tool was tested, the first version of the tool was developed for and tested in a video-based study. In the remainder of this section, we describe the robot used in our study, the experimental design, the participants, the evaluation tool and experimental results.

3.1 The Robot

The robot used in our studies was Pepper, a humanoid robot with 20 degrees of freedom (DOF), a height of 1.2 m and a weight of 28 kg. There are two DOFs in the head (pan and tilt), two DOFs in the hips, one DOF in the knee and three DOFs in the base. Each arm has six DOFs: two DOFs in the shoulder, two DOFs in the elbow, one DOF in the wrist and one DOF in the hand. The robot is equipped with three multi-directional wheels, four directional microphones, six touch sensors, several infrared sensors, laser sensors and sonar sensors, and two loudspeakers. There are three cameras: two RGB cameras (forehead and mouth) and one 3D camera located behind the eyes (Pandey & Gelin, 2018).

3.2 Experimental Design

To create more accurate real world scenarios of HRI, nonverbal gestures were included in the video-recorded scenarios. Gestures accompanied by speech help to convey meaning and semantic information in the social interaction (McNeill, 1992). The robot gestures involved head gestures such as head nodding and head shaking as well as arm gestures that follow the terminology used by McNeill (1992): (1) deictics, (2) beats, (3) iconics, and (4) metaphors. Deictic gestures are gestures pointing at objects or abstract space in the environment. Beat gestures are simple up-and-down or back-and-forth hand movements keeping the rhythm of speech and indicating notable points. Iconic gestures are gestures depicting images or actions.

Metaphorics represent abstract concepts or objects such as moving one hand toward the shoulder to refer to the past.

To gain a better understanding of how these gestures affect the sense of safety and security, we conducted a between-subjects video-based study using the Pepper humanoid robot. The study considered four different scenarios comprising daily life activities in which older people may be engaged. The participants' sense of safety and security was measured through questionnaires administered after having watched four videos featuring Pepper using *one* of the following variations of nonverbal gestures: only arm gestures (configuration 1), only head gestures (configuration 2), head and arm gestures (configuration 3) and no gestures (configuration 4). Detailed explanations about the configurations are given in Section 3.2.1.

The scenarios used in this study were recorded as short videos which were between 20 and 30 seconds long. We selected four scenarios from Cortellessa et al. (2008) which presented a video-based evaluation to compare older people's perception of socially assistive domestic robots in two different cultural backgrounds: Italian and Swedish user groups. Two of the selected scenarios were proactive (i.e., the robot was the initiator) and two of them were on-demand scenarios (i.e., the user was the initiator). Detailed explanations of the scenarios are given in Section 3.2.2.

3.2.1 Robot Configurations

The selected configurations of nonverbal gestures used in this video-based study are briefly described below.

Configuration 1: The robot uses only arm and hand gestures (six DOFs in each arm) including deictic, beat, metaphoric and iconic gestures.

Configuration 2: The robot uses only head gestures (two DOFs in the head which are pan and tilt) including head nodding and shaking. The head nodding gesture is used for agreement and the head shaking gesture for disagreement.

Configuration 3: The robot uses both head and arm gestures (14 DOFs, i.e., two arms and head DOFs) in the same scenario.

Configuration 4: No gestures; the Pepper robot does not use any of its DOFs, i.e., Pepper performs no nonverbal gestures while speaking.

3.2.2 Videos

The selected scenarios used in this video-based study, which are taken from Cortellessa et al. (2008), are briefly described below. Scenario numbers 1 and 2 represent proactive situations; scenario numbers 3 and 4 are on-demand interactions.

Scenario 1: Environmental safety. *The actor is sitting on the sofa, watching TV. Meanwhile, in the kitchen, the sauce on the stove is overcooking. The robot moves toward the actor and says: "The pot is burning. You should turn it off." The actor immediately goes to the kitchen and turns the stove off.* (Figure 1a)

Scenario 2: Reminding analysis. *The actor is in the kitchen. He is about to have breakfast. When he puts the pot on the stove, the robot says: “You cannot have breakfast now. You have an appointment for a medical analysis.” The actor answers: “You’re right. I have forgotten all about it!”* (Figure 1b)

Scenario 3: Finding objects. *The actor is sitting on the sofa and picks up a magazine to read. Suddenly, he realizes that his glasses are not on the table in front of him. The actor calls the robot and asks: “Where are my glasses?” The robot answers: “Just a minute, I am checking” and then the robot answers: “The glasses are in the kitchen.” The actor goes to the kitchen and gets the glasses.* (Figure 2a)

Scenario 4: Reminding about medication. *The actor is sleeping on the sofa, and suddenly wakes up. He does not realize what time it is, and thus he asks the robot. The robot answers: “It is four o’clock.” The actor does not remember whether or not he took his medicine after lunch, and asks the robot. The robot answers: “Yes, you took it.”* (Figure 2b)

Figures 1 and 2 show snapshots from each scenario and robot configuration.

Fig. 1: Snapshots from the proactive scenarios (a) Scenario 1 - Environmental safety, the robot uses both arm and head gestures (configuration 3), (b) Scenario 2 - Reminding analysis, the robot uses only head gestures (configuration 2).

3.3 Participants

In Akalin et al. (2017), we reported the initial results from the video-based study including 100 participants. In this chapter, we include 24 additional participants in the analysis, i.e., in total 124 participants. There were 58 males and 66 females, whose ages ranged from 14 to 65 years ($\mu_{age}=35.44$, $\sigma_{age}=10.55$) who took part in the online survey. The advertising for the study was carried out in social media and through mailing lists. The numbers of participants for configurations 1 to 4

Fig. 2: Snapshots from the on-demand scenarios (a) Scenario 3 - Finding objects, the robot uses only arm gestures (configuration 1), (b) Scenario 4 - Reminding about medication, the robot uses no gestures (configuration 4).

were as follows: 46, 28, 25, 25 participants. In our online survey, participants could select any of the configurations (1-4). The most selected configuration was the first one (configuration 1). As reported in Section 3.2, each participant watched four videos featuring Pepper using the same configuration. The participants' familiarity with robots was as follows: 31% of them had seen a real robot before but were not familiar with robots, 16% had already interacted with robots, 23% worked with robots and 30% had previously seen a robot on TV/Internet.

3.4 Questionnaires

Using the literature study presented in Section 2, we developed a first version of a questionnaire for evaluating the sense of safety and security. The questionnaire could be divided into four different areas: sense of safety, sense of security, acceptance, and emotions.

The questionnaire batch used for data collection in the video-based study consisted of one socio-demographics form plus four separate sections. In the socio-demographics form, the participants were asked about gender, age, educational level, country of residence and their familiarity with robots. A brief explanation of the other sections is given below:

Section 1: Sense of safety. Six questions were designed on a five-point semantic differential scale to assess sense of safety with regard to the four videos that were presented. The questionnaire included Section V from Bartneck et al.'s 2009 Godspeed questionnaire series (anxious–relaxed, agitated–calm, quiescent–surprised) and the following items: threatening–safe, uncomfortable–comfortable and predictable–unpredictable.

Section 2: Sense of security. Six questions were designed in a five-point semantic differential scale to assess sense of security in response to the four videos that were presented. We designed a questionnaire for the sense of security including the items: insecure–secure, unfamiliar–familiar, fear–ease, unreliable–reliable, unnatural–natural, lack of control–in control. The questionnaire items were decided based on the gerontology studies summarized in Section 2.2.

Section 3: Acceptance. There were seven questions rated on a five-point Likert scale, ranging from ‘Strongly disagree’ to ‘Strongly agree’ to assess the acceptability of the robot. Four of them were asked after each video and three of them were asked at the end of the survey. These questions were taken from Fischinger et al. (2016) and the trust construct of the Almere model (Heerink et al., 2010).

Section 4: Emotions. Self-Assessment Manikin (SAM) by Bradley & Lang (1994), was used to evaluate the participants’ emotions. Manikin is a scale for assessing emotions in the valence-arousal emotion space (Russell, 1980) which ranges from unpleasant to pleasant on the valence scale and calm to excited on the arousal scale. In this study, a nine-point semantic scale was used. At the end of the survey, an additional text field was provided allowing for free comments. The questions are given in Table 1.

Table 1: The questions asked in the online survey.

	Questionnaire items	Scale
Scenarios	The scenario seems realistic, one can encounter this scenario in the daily life.	1 = Strongly disagree 5 = Strongly agree
	I liked the scenario.	
	I can use the robot for a long period in my home.	
	I can imagine having a robot taking care of me.	
Sense of safety	Threatening–safe, anxious–relaxed, agitated–calm, quiescent–surprised, uncomfortable–comfortable, unpredictable–predictable	1 to 5
Sense of security	Insecure–secure, unfamiliar–familiar, fear–ease, unreliable–reliable, unnatural–natural, lack of control–in control	1 to 5
Emotions	Unpleasant–pleasant, calm–excited	1 to 9
Acceptance	I think the robot would be helpful in my home.	1 = Strongly disagree 5 = Strongly agree
	I would trust the robot if it gave me advice.	
	I would follow the advice the robot gave me.	

3.5 Procedure

The data was collected using an online survey in which the participants watched four videos featuring a robot and an older person. The videos and questionnaires were in English¹. The participants were provided with a short introduction about the survey and filled out the socio-demographics form. Then, the video sessions started. The participants were asked to watch the four videos one by one. At the end of each video, a short questionnaire was used to assess the participants' views on the scenario and the robot. After having seen all the videos, the participants filled out four questionnaires to assess their sense of safety, sense of security, emotions and acceptance. No explanation of the real aim of the study was given in order to avoid influencing and biasing the participants.

3.6 Experimental Results

To compare the effects of nonverbal gestures on the sense of safety, sense of security and acceptance, a one-way Analysis of Variance (ANOVA) was applied. The results seem to indicate that the participants did not notice the gestures of the robot (Sense of security $F(3,120) = 0.49$, $p < 0.69$, sense of safety $F(3,120) = 0.50$, $p < 0.68$, and acceptance $F(3,120) = 0.96$, $p < 0.41$). Throughout the online survey, we did not mention anything about the gestures. We expected that the gestures would affect the participants, but the results show that there is no statistically significant difference between the four configurations for any of the measures and only a few participants commented on the gestures in the free text field. One reason for the lack of a statistically significant difference between the four configurations could be that the participants were concentrating on the scenarios and the idea of using robots in homes. Another explanation might be the choice of conducting a video-based study online with participants recruited through mailing lists and social media. Some participants may have watched the videos on a smart phone screen and never noticed the robot's gestures. In addition, we also investigated whether the participants' response to the questions within the scenario section varied as a result of having seen on-demand or proactive scenarios. The results of the one-way ANOVA tests show that the participants liked the on-demand scenarios more than the proactive scenarios, $F(1,494) = 4.89$, $p < 0.05$ ($\mu_{proactive} = 3.76$, $\sigma_{proactive} = 0.93$ and $\mu_{on-demand} = 3.95$, $\sigma_{on-demand} = 0.89$).

In the remainder of this section, we present the results from measuring sense of safety, sense of security, as well as the combined results for sense of safety and sense of security, acceptance and emotions.

¹ The videos and questionnaires used during the video-based study: <https://bit.ly/2DkiOHo>.

3.6.1 Sense of Safety

The sense of safety questionnaire consisted of six items (threatening–safe, anxious–relaxed, agitated–calm, quiescent–surprised, uncomfortable–comfortable, unpredictable–predictable). We conducted a reliability analysis to check the internal consistencies within the items in the questionnaire. Cronbach’s α was used for measuring the internal consistencies within the items of a test or scale (Cronbach, 1951). The α coefficient ranges from 0 to 1 showing the overall assessment of a measure’s reliability and a value over 0.7 is considered as acceptable.

The Cronbach’s α for all participants and configurations including all items was 0.79. Comments provided in the free text field showed that many participants were confused about the quiescent–surprised scale so we excluded this item and recalculated the Cronbach’s α . The final Cronbach’s α value was 0.87. This indicates that the questionnaire items had a good internal consistency. The calculated Cronbach’s α values for each configuration and in total are given in Table 2a, where the new Cronbach’s α shows the values after the quiescent–surprised item is excluded.

The semantic differential scale descriptive statistics (mean and standard deviation) for each configuration and in total can be seen in Table 2b. The results show that the participants’ experience was on the positive side for the bipolar adjectives used in the sense of safety questionnaire. This can also be seen in Table 3, which shows how the number of responses varied from the negative side to the positive side.

Configuration	Cronbach’s α	New Cronbach’s α	Configuration	μ	σ
c1	0.57	0.78	c1	3.83	0.95
c2	0.84	0.85	c2	3.67	0.96
c3	0.86	0.93	c3	3.84	1.22
c4	0.81	0.86	c4	3.70	1.02
total	0.79	0.87	total	3.77	1.02

(a) Cronbach’s α values.

(b) Descriptive statistics.

Table 2: Sense of safety statistics for each configuration and in total. Five-point semantic scale.

3.6.2 Sense of Security

The Cronbach’s α value for all participants and all configurations was 0.87, which shows that the questionnaire has good internal consistency. The internal consistencies for each configuration and in total are given in Table 4a. The semantic differential scale descriptive statistics of sense of security (mean and standard deviation) for each configuration can be seen in Table 4b. The results show that the participants’ experience was on the positive side also for the bipolar adjectives used in the sense

Table 3: Number of responses for the sense of safety questionnaire.

	1	2	3	4	5	
threatening	1	4	20	52	47	safe
anxious	2	7	29	53	33	relaxed
agitated	2	4	20	51	47	calm
quiescent	12	28	48	28	8	surprised
uncomfortable	4	11	24	46	39	comfortable
unpredictable	2	5	40	52	25	predictable

^a The numbers in columns 1 - 5 show the response distribution.

of security questionnaire. This can also be seen in Table 5, which shows how the number of responses varied from the negative side to the positive side.

Configuration	Cronbach's α	Configuration	μ	σ
c1	0.83	c1	3.62	0.97
c2	0.88	c2	3.72	1.00
c3	0.93	c3	3.72	1.24
c4	0.83	c4	3.49	1.10
total	0.87	total	3.64	1.07

(a) Cronbach's α values.

(b) Descriptive statistics.

Table 4: Sense of security statistics for each configuration and in total. Five-point semantic scale.

Table 5: Number of responses for the sense of security questionnaire.

	1	2	3	4	5	
insecure	3	3	26	50	42	secure
unfamiliar	6	23	33	38	24	familiar
fear	1	5	33	46	39	ease
unreliable	0	13	34	44	33	reliable
unnatural	12	27	40	35	10	natural
lack of control	3	16	29	46	30	in control

^a The numbers in columns 1 - 5 show the response distribution.

3.6.3 Sense of Safety and Security

We also calculated the Cronbach's α for sense of safety and security by using all the items (excluding quiescent-surprised, as mentioned before) in both questionnaires (the sense of safety and the sense of security). The Cronbach's α value for all participants and all configurations was 0.91, which again shows that combining the questionnaires resulted in a good internal consistency.

3.6.4 Emotions

In the valence-arousal emotion space, each emotion can be placed on a 2D graph with a horizontal axis (valence) and a vertical axis (arousal) where valence ranges from unpleasant to pleasant, and arousal ranges from calm to excited (Russell, 1980). The emotion section of the questionnaire rated emotional states using SAM to place emotions onto Russell's 2D graph. The graph has four quadrants: high valence-high arousal (HVHA), low valence-high arousal (LVHA), low valence-low arousal (LVLA), and high valence-low arousal (HVLA). The first quadrant, HVHA, includes emotions such as happy and excited, the second quadrant, LVHA, includes emotions such as angry and frustrated, the third quadrant, LVLA, includes emotions such as sad and bored, and the fourth quadrant, HVLA, includes emotions such as calm, pleased and relaxed. Based on the SAM ratings, the average of the rated emotional states was in the HVLA quadrant. As shown in Figure 3, the majority of the participants felt high valence and low arousal about the robot videos.

3.6.5 Acceptance

The descriptive statistics from the acceptance questionnaire are provided in Table 6 and Table 7 shows the distribution of responses. Interestingly, even though the participants did not notice the gestures according to the one-way ANOVA, the mean had the lowest values for every question in the c3 configuration (head and arm gestures). This may imply that the robot should have enough gestures, but this should be further investigated.

4 Revising and Validating the Tool for Evaluating Sense of Safety and Security in Social HRI: Older People Interacting with Pepper

In the first study presented in Section 3, we developed a questionnaire for measuring sense of safety and sense of security. As shown in Section 3.6.3, the Cronbach's α value was high for the combined safety and security questionnaire. In this second study, we used a revised and smaller version of the combined questionnaire. The

Fig. 3: SAM results on the 2D valence-arousal space.

Table 6: Acceptance Likert scale descriptive statistics for each configuration and in total.

Question	c1	c2	c3	c4	Total
I can imagine using the robot for a long period in my home.	$\mu = 3.74$ $\sigma = 0.95$	$\mu = 3.42$ $\sigma = 1.23$	$\mu = 3.28$ $\sigma = 1.33$	$\mu = 3.44$ $\sigma = 1.29$	$\mu = 3.52$ $\sigma = 1.17$
I can imagine having a robot taking care of me.	$\mu = 3.87$ $\sigma = 0.86$	$\mu = 3.68$ $\sigma = 1.12$	$\mu = 3.44$ $\sigma = 1.26$	$\mu = 3.72$ $\sigma = 1.20$	$\mu = 3.71$ $\sigma = 1.08$
I think the robot would be helpful in my home.	$\mu = 3.83$ $\sigma = 0.93$	$\mu = 3.64$ $\sigma = 1.25$	$\mu = 3.48$ $\sigma = 1.26$	$\mu = 3.76$ $\sigma = 1.23$	$\mu = 3.70$ $\sigma = 1.13$

^a 1 = Strongly disagree, 5 = Strongly agree.

questionnaire was tested with older people at the Senior Festival in Örebro, Sweden. The robot used in the study was, once again, the Pepper robot. At the Senior Festival, we had a stand where older people had a chance to come and interact with the robot. Since the participants could freely interact with the robot, the items unnatural–natural and unpredictable–predictable were not suitable for the interaction and were therefore excluded from the questionnaire. We replaced the adjective *agitated* with *scary* to make it clearer, thus we excluded fear–ease since scary and fear are quite similar words. The exclusion of the item quiescent–surprised has already been discussed (confusion of the item). In this way, four items were removed and eight items remained (see Table 8).

Table 7: Number of responses for acceptance questionnaire.

	1	2	3	4	5
I can imagine using the robot for a long period in my home	10	18	15	60	21
I can imagine having a robot taking care of me	4	18	17	56	29
I think the robot would be helpful in my home	6	16	19	51	32

^a The numbers in columns 1-5 show the response distribution. 1 = Strongly disagree and 5 = Strongly agree.

The aim of the study was to understand older people’s sense of safety and security regarding social robots. Approximately 80 older people visited our stand and interacted with the robot. During the interaction with Pepper, they could, for example, speak with the robot, dance with the robot or watch the robot dancing. After the interaction, we asked them to fill out our questionnaire. Even though they enjoyed interacting with the robot and found it very cute and interesting, many interactants declined to fill out the questionnaire. In total, 44 older people ($\mu_{age}=70.08$, $\sigma_{age}=8.30$) filled out the questionnaire but only 36 of them (25 females and 11 males) answered all the questions.

For the majority of the participants this was the first time they had interacted with a robot. Eight of them had interacted previously with a robot while participating in HRI experiments conducted at Örebro University.

Figure 4 shows two photos from the Senior Festival. The questionnaire administered was in Swedish and had 13 questions including the demographics questions (age and gender). The questionnaire and questionnaire results are provided in Tables 8 and 9. We conducted a reliability analysis to check the internal consistency of the items of our revised questionnaire. The Cronbach’s α for the participants who filled out the entire questionnaire was 0.89. Hence, the revised questionnaire has a good internal consistency and can be used in HRI scenarios.

5 The Initial Model of Sense of Safety and Security

In order to measure the sense of safety and security, we propose a model that considers different properties of the user profile as well as different robot properties. This model includes two parts: 1) human-related factors; and 2) robot-related factors. The factors are determined based on the literature provided in Section 2 and the insights obtained while conducting the user studies.

Only the human-related factors were taken into consideration in the questionnaires used in the studies discussed in Sections 3 and 4. Therefore, we have designed an initial model of sense of safety and security which is based on only human-

Fig. 4: Two photos from the Senior Festival.

Table 8: The revised questions used at the Senior Festival.

Questionnaire items	Scale
While interacting with the robot, I felt: Insecure–secure Anxious–relaxed Uncomfortable–comfortable lack of control–in control	1 to 5 (Semantic scale)
I think the robot is: Unsafe–safe Unfamiliar–familiar, Unreliable–reliable, Scary–calming	1 to 5 (Semantic scale)
Using a robot would make my life easier. I think the robot would be helpful in my home.	1 = Strongly disagree 5 = Strongly agree
Familiarity with robots	This is the first time I have seen a real robot. /I’ve interacted with a robot.

related factors. In the remainder of this section, we discuss human-related factors in Section 5.1 while the proposed model of sense of safety and security based on human-related factors is provided in Section 5.2. Finally, the robot-related factors are elaborated upon in Section 5.3. More user studies are needed to cover all the factors.

Table 9: Senior Festival questionnaire descriptive statistics.

Item	μ	σ
While I interacted with the robot I felt:		
Insecure–secure	3.67	0.79
Anxious–relaxed	3.53	0.88
Uncomfortable–comfortable	3.61	1.23
lack of control–in control	3.25	1.30
I think the robot is:		
Unsafe–safe	3.72	1.09
Unfamiliar–familiar	3.03	1.21
Unreliable–reliable	3.81	0.92
Scary–calming	3.56	0.97
Using a robot would make my life easier	3.22	1.02
I think the robot would be helpful in my home	3.14	0.99

^a Descriptive statistics are presented on different scales (see Table 8).

5.1 Human-related Factors

Feeling comfortable during the interaction has been reported to be one of the key issues in HRI scenarios (Dautenhahn et al., 2006). The human comfort was taken into account in different HRI scenarios, such as by addressing the effects of using a simple hand-held device to measure the participant’s comfort level with changing robot behaviors (Koay et al., 2006), and comfortable distance in a scenario involving a robot following a human (Koay et al., 2006). Lauckner et al. (2014) attempted to determine the threshold of comfort for frontal and lateral distances in human-mechanoid interaction in a hallway scenario. It was also argued that human comfort can change with different scenarios, robots, tasks, application areas as well as users (Dautenhahn, 2007).

A lack of sense of safety and security affects people’s feeling and is associated with emotional responses such as fear, stress, anxiety, surprised and anger (Nonaka et al., 2004; Zheng et al., 2016). Our semantic differential scale covered these items as: fear–ease, anxious–relaxed, quiescent–surprise, scary–calm. In Section 5.2, we included these items in our model (see Figure 5).

Having experience of and familiarity with robots facilitates a more natural HRI according to, e.g., De Graaf & Allouch (2013). To eliminate the novelty effect of the robot and to gain familiarity with it, long-term studies are required. Throughout the long-term interaction, novelty effects wear off and fade away over time, causing human expectations and behaviors to change (Sung et al., 2009) whereas the short-term interaction with a robot may result in a trade-off between the robot’s verbal behavior and the desired positive impact on learning gains with a robot tutor (Kennedy et al., 2016). Previous research in HRI has demonstrated that a long-term interaction between a user and a robot can impact the attitude and behavior of the person and hence the user experience (Leite et al., 2013).

Being in control is one of the most important factors affecting the sense of security among older people (Boström et al., 2013, 2016). We use the term ‘sense of control’ as “the user feels that he/she is in charge of the system”. The sense of control is also known as ‘sense of agency’ which is defined as a *feeling of control over actions and their consequences* (Moore, Moore). In human-computer interaction, sense of agency has been taken into account in one of Shneiderman (1992)’s golden rules of interface design. The seventh rule (Support internal locus of control) is based on the idea that operators desire the sense of being in charge of an interface and that the interface responds to the operators actions. In HRI, the user’s sense of control during the interaction with a robot was found to be linearly related to the expected level of autonomy (Chanseau et al., 2016).

Trust has been remarked as being an important factor affecting older people’s sense of safety and security (Petersson & Blomqvist, 2011) as well as in HRI (Charalambous et al., 2016; Salem et al., 2015). Trust is indicated as being one of the factors responsible for the increased acceptance of robots and as contributing to the establishment of effective relationships between humans and robots, as well as to humans’ willingness to cooperate with a robot (Salem et al., 2015).

In Section 5.2, we described our development of an initial model which categorizes the items in the combined sense of safety and security questionnaire into comfort, emotional responses, experience, sense of control, and trust (see Figure 5).

5.2 The Model of Sense of Safety and Security

In this section, we first present the initial model (Figure 5) that was designed intuitively. The model was updated after an Exploratory Factor Analysis (EFA) of the video-based study, and validated in a Confirmatory Factor Analysis (CFA) of the older people’s study. The Kaiser-Meyer-Olkin (KMO) test indicates the suitability of the data for factor analysis (FA). The result of the KMO test suggests that both the video-based study and the older people study was suitable for FA; 0.91 and 0.86 respectively.

To discover possible underlying factors and to check if these factors match with our initial model, we conducted an EFA by using the R psych package. Ten items (threatening–safe, anxious–relaxed, agitated–calm, uncomfortable–comfortable, unpredictable–predictable, insecure–secure, unfamiliar–familiar, unreliable–reliable, unnatural–natural, lack of control–in control) of the sense of safety and sense of security questionnaires used in the video-based study were subjected to an EFA with varimax rotation and extraction using minres (ordinary least squares) with five factors. We followed Jolliffe’s criterion and retained all factors with eigenvalues greater than 0.7. The results of the EFA are presented in Table 10 and Figure 6. This model showed a good fit (Goodness of Fit Index (GFI) = 0.937 and Comparative Fit Index (CFI) = 0.974). The video-based study included the fear - ease item and the older people study included the scary - calming item. In order to ensure consistency between them, we excluded the item fear–ease when conducting the EFA. As already

Fig. 5: The initial model of sense of safety and security based on human-related factors.

discussed, the quiescent–surprised item was excluded due to confusion. The exclusion of the item was further motivated by the KMO test which also showed that the value of this item for Measure of Sampling Adequacy was 0.45, which is lower than the minimum acceptable value, 0.5.

Table 10: Exploratory factor analysis factor loadings concerning the items of the sense of safety and sense of security.

Questionnaire items	Factors				
	F1	F2	F3	F4	F5
threatening–safe	0.59	0.14	0.31	0.18	0.20
anxious–relaxed	0.83	0.33	0.15	0.14	0.20
agitated–calm	0.64	0.27	0.33	0.18	0.14
uncomfortable–comfortable	0.61	0.15	0.32	0.23	0.37
unpredictable–predictable	0.27	0.30	0.46	0.19	0.17
insecure–secure	0.47	0.26	0.75	0.16	0.31
unfamiliar–familiar	0.25	0.83	0.27	0.11	0.14
unreliable–reliable	0.33	0.27	0.33	0.14	0.68
unnatural–natural	0.29	0.49	0.10	0.23	0.37
lack of control–in control	0.24	0.17	0.17	0.93	0.14

^a F1 = comfort, F2 = experience, F3 = sense of security, F4 = trust, and F5 = sense of control.

Fig. 6: Five factors model, item loadings to factors.

In our initial model, we had the categories: comfort, emotional responses, experience, trust and sense of control. After conducting the EFA, we updated our model's factors and items. For example, the items under emotional response in the initial model clustered with the item uncomfortable-comfortable. However, we kept the naming comfort for that category (shown in the Figure 8). The factor three (F3 in Figure 7) had two items: unpredictable-predictable and insecure-secure. We named that factor as sense of security (see the item loadings and namings in Figure 6).

We verified the factor structure obtained using the video-based data on the older people data by conducting CFA. For CFA, we used the R lavaan package. CFA for the model shown in Figure 8 on the older people data again showed a good fit (GFI = 0.882 and CFI = 0.944).

5.3 Robot-related Factors

We categorized robot-related factors that affect the sense of safety and security as gestures, functional properties of the robot, physical properties of the robot and social properties of the robot. Gestures can be verbal, nonverbal and gaze; functional properties are ease of use, autonomy and performance; physical properties are anthropomorphism, embodiment and size of the robot; and social properties are personality of the robot and friendliness.

The gestures of a robot will make the interaction more natural and comprehensible, i.e., similar to human-human interaction. The manner in which a robot reacts during an interaction with a human may affect the human's perception, well-being, the sense of support and security, and willingness to interact. A responsive robot (robot with gestures) may facilitate an increased sense of security and also increase the willingness to use the robot in stressful settings (Birnbbaum et al., 2016). Despite the studies investigating gestures and gaze, it has not yet become apparent how the robot should behave to achieve natural communication resulting in a safe and secure relationship between a robot and an older person (Muto et al., 2009).

Fig. 7: EFA item loadings on factors.

Fig. 8: Updated model of sense of safety and security.

Using assistive technologies in elder care might contribute to promoting a sense of safety and security. However, using these technologies can be challenging for older people. Therefore, ease of use is one of the concerns that should be addressed (Yusif et al., 2016). Another concern is the performance of the robot, since higher performance of robots is perceived as safer (Kamide et al., 2013). The autonomy of the robot is another issue that should be considered.

Humans attribute human-like features to the agents (e.g., robots) because it allows the agents to become more familiar, understandable and predictable (Epley et al., 2007). Anthropomorphism is important for helping humans to become familiar with robots. On the other hand if a robot resembles a human greatly but still remains an unnatural copy, the person's response to this agent would shift from empathy to revulsion or fear. This emotional response is called 'uncanny valley' (Mori, 1970). Wu et al. (2012) compared different robots and their results showed that small humanoid robots with some traits between human/animal and machine were appreciated more by their older participants. Figure 9 summarizes the robot-related factors.

It is worth mentioning that the environment also affects the sense of safety and security, but it is not in the scope of this study. There are studies examining the effect of the environment on sense of safety and security.

Physical properties	Functional properties	Gestures	Social properties
<ul style="list-style-type: none"> • Anthropomorphism • Embodiment • Size 	<ul style="list-style-type: none"> • Ease of use • Autonomy • Performance 	<ul style="list-style-type: none"> • Verbal cues • Nonverbal cues • Gaze 	<ul style="list-style-type: none"> • Personality • Friendliness

Fig. 9: Robot-related factors of sense of safety and security.

6 Discussion and Conclusion

Modern assistive technology can contribute to improving the quality of life of the older population, and to promoting older people's sense of safety and security (Yusif et al., 2016). Social robots have the potential to be used in elder care to preserve independence and to relieve the burden of caregivers. To use social robots in homes and care facilities, understanding the underlying reasons for the acceptance or rejection of this technology is crucial. While physical safety and security have received particular attention in the robotics literature, little research has focused on examining the feeling of safety and security as a determining factor for acceptance of robots

in elder care. Feeling safe and secure can increase older people's quality of life and well-being (Fonad et al., 2006). Social robots' ability to foster secure relationships with older people is an important aspect of effective HRI. We believe that the sense of safety and security is a key requirement for HRI which should be addressed in a deeper sense, considering all its aspects and implications for using robots in elder care. In this research, we attempted to identify the factors influencing the sense of safety and security in HRI, especially for older person-robot interaction. To address this, besides consulting the gerontology literature, we conducted two user studies.

Measuring the sense of safety and security is a challenging task since there is no general consensus about the definition of the term and there are many factors affecting an individuals' sense of safety and security. The factors affecting the sense of safety and security can be quite personal; every individual can perceive it differently based on their personal attributes such as background and personality. In the context of HRI, there are many factors affecting the sense of safety and security including subjective preferences as well as a robot's properties. We adopted a categorization of the components of sense of safety and security: human-related factors and robot-related factors. We provided a thorough review of the meaning of safety and security in HRI and gerontology. The review resulted in an evaluation tool and a model of sense of safety and security. The presented model is based on only human-related factors, since we did not vary robot-related factors in our user studies.

The model was the foundation for a tool that can be used for evaluating the sense of safety and security in social HRI. The tool was applied in a between-subject video-based study in which the Pepper humanoid robot interacted with a person. This study had limitations since the experience was not derived from direct interaction with a robot; however, this was a deliberate choice in order to control the experimental setup. In the online video-based study, participants watched four different scenarios showing different daily life activities that older people may engage in. The scenarios were of a proactive and on-demand nature.

The Cronbach's α value for the sense of safety and security was 0.91, which indicates that the questionnaire items had a good internal consistency.

Using the results of the online video-based study, we revised the questionnaire based on the participants' recommendations and the statistical analysis; the items that were negatively correlated with other factors were removed. We conducted a second controlled study in which older people could interact freely with Pepper. After the interaction, they filled out the revised questionnaire assessing the sense of safety and security. We further analyzed the user studies by applying EFA and CFA and updating our intuitive model.

Our experimental results from the two studies, which comprised 160 participants in total, suggest that the questionnaires assessing sense of safety, security, and the combination thereof, are suitable for use within the social HRI domain. Moreover, the model suggested can be used for evaluating the sense of safety and security in older person-robot interaction. However, the model is not complete yet. Robot-related factors require a much larger study with other robots and/or variations in functionality, allowing for gestures, functional, physical and social properties of the robot to be evaluated and compared. Thus, a possible future direction of the study

could be to implement an experimental design that reveals which characteristics of robot systems affect the perceived sense of safety and security. Such insights could be used for updating the initial model of sense of safety and security that was outlined in this chapter.

7 Acknowledgment

This work has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 721619 for the SOCRATES project.

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