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Development of a Comprehensive Design Guideline to Evaluate the User Experiences of Meal-Assistance Robots considering Human-Machine Social Interactions

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ABSTRACT
Meal-assistance robots (MARs) help feed meals to users with disabilities or who need help consuming their meals. Although such MARs have been introduced in various fields, guidelines for evaluating MARs are limited. This study aims to develop comprehensive guidelines to assess the user experience (UX) of MAR designs considering its social interaction characteristics between humans and robots. Participants from three groups (patients, doctors, and caregivers) with different perspectives on MARs were recruited and a focus group interview was conducted to collect their UXs with MARs. The three groups showed different UXs with MARs in user interface design, robot arm motion, and safety and mobility. In addition, based on the literature review, eight UX features (usability, emotion, value, naturalness, assistance, acceptance, personality, and culture) are proposed to evaluate MAR interfaces. The proposed comprehensive design guideline will be particularly useful in evaluating and designing the UX of MARs.

1. Introduction

People with physical or mental disabilities have a special need for assistance from caregivers to perform activities of daily living (ADL), which refers to eating, bathing, dressing, and so on. Various assistive robots have been developed to enhance the physical or cognitive abilities of children, the elderly, or disabled people with various challenges, such as cerebral palsy (Raya et al., 2015), autism (Martinez-Martin et al., 2020), and Alzheimer's disease (Tapus et al., 2009). These assistive robots were designed with various technical and functional characteristics, including learning and applying knowledge, mobility, control, vision, attention, memory, and communication capabilities. Many social robots were partially or fully remote controlled to simulate advanced capabilities. In addition, some robots were designed with a screen to represent the head or face to communicate with patients and the bodies were consisted of physical motors or sensors to perform various tasks. For caregivers, one of the most challenging tasks is feeding the patients. The act of helping someone consume a meal is a process that must be performed for every meal of every day, and it is the most time-consuming and labor-intensive activity for caregivers. Therefore, a meal-assistance robot (MAR), which autonomously feeds a person with a disability, is being developed and expected to play an important role in interacting with a patient on behalf of a caregiver. Although many types of MARs have been introduced and made available to the public, research on improving the interactions between the MARs and users (patients or caregivers) is still lacking. Previous studies mainly focused on developing the functionalities of MARs (Bhattacharjee et al., 2020), such as grabbing the food and placing it into the user's mouth. It is of course important to develop various functionalities of MARs from the technology point of view. Still, since MAR functions are executed through the interaction between the user and the robot, it is more necessary to reflect the user's point of view. In other words, to increase user acceptance of MARs, what functionality should be additionally developed and from what points of view the functionality should be evaluated. The importance of user experiences (UX) and social interactions between the MARs and users have been emphasized on a gradual basis (Alenljung et al., 2017; Bhattacharjee et al., 2020; De Graaf & Allouch, 2013; Nishiwaki & Yano, 2008; Tanaka et al., 2010).

UX refers to the user's feeling while utilizing specific systems, products, services, devices, and so on in a specific environment (Park & Han, 2013; Preece et al., 2015; Rivero & Conte, 2017; Savioja et al., 2014). UX for interactive service products has been widely studied, and the research found that usability, affect, and user value are the major factors affecting

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UX (Kim et al., 2016; Park & Han, 2013, 2018; J. Park et al., 2013). From the perspective of HRI, UX is the feeling obtained while interacting with a robot; it is an important factor in determining user acceptance for a robot (De Graaf & Allouch, 2013). For the overall human-robot interaction (HRI) field, UX starts with understanding the task and environment for which the robot is intended. Lindblom and Andreasson (2016) identified three key challenges in the incorporation of UX in HRI: (1) there is a need to employ an iterative design method, (2) the UX designers must set the goals and make sure that they are not overlooked, and (3) the robot developers must know how to adopt the results of UX evaluations in designing HRI. In addition, UX considers the social impact that the robot can have on the users who operate and interact with it. The achieved UX in the natural context will promote the utilization of an assistive robot in society that will also determine the robot's success (Jost et al., 2020). In general, socially assistive robots with high degrees of HRI perform the roles of peers or companions, and they require close social, emotive, and cognitive interactions with the users (Goodrich & Schultz, 2007). Thus, MARs, utilized for nursing care and rehabilitation, are required to have social skills that contribute to making user interactions more convenient (Dautenhahn, 2007). Therefore, deep consideration of UX and social skills is essential in designing MARs.

This study aims to develop a comprehensive design guideline for the UX elements of MARs by considering their social interactions with the users. The guideline for UX evaluations is developed by focusing on nine design issues of a social robot (comparative media, naturalness, user expectation, quality, relationship, teamwork, personality, culture, and acceptance issues), as first proposed by Breazeal (2004). The most effective way to collect the data necessary to develop a comprehensive UX guideline for an MAR is through the extensive literature review and focus group interviews (FGIs). FGIs are conducted with 15 participants including spinal cord injury patients who need MAR use, caregivers who provide dietary assistance to spinal cord injury patients, and doctors who treat spinal cord injury patients; various experiences related to the utilization of MARs are collected. By reflecting and analyzing the collected experiences, based on the design issues specified by Breazeal (2004), the guideline with multiple criteria for UX evaluations specific to MARs is developed.

2. Literature review

2.1. Commercial and academic Mars

Although different kinds of interfaces and tools are being introduced in commercial markets, the uniformity between the interfaces of MARs lacks because many researchers studied different patients and made robot designs for specific patient groups. (Bhattacharjee et al., 2020). Most MARs have been developed in the United States; in addition, many MARs have been manufactured in the United Kingdom and Japan. Table 1 shows a list of commercial MARs. The interface column indicates the controller's interface type that selects and inserts the food into the mouth. Various interfaces exist, such as physical buttons, touch interfaces, rocker switches, and joysticks (Figure 1) (Obi, 2021; Patterson Medical, 2021). Some robots are compatible with multiple interfaces to change and utilize the desired interfaces, which are indicated in the interchangeability column. The interchangeability in Table 1 indicates whether the interfaces are compatible and can be selected via the user's. The tools that robots use to pick up food are generally spoons and forks; there are robots with a pusher to place the food onto the spoon.

In addition to the commercialized robot market, new MAR technologies are being studied considering various interfaces, tools, and food items (Table 2). In the case of interfaces, the trend is to study more advanced technologies than commercialized robots, such as brain computer interface (BCI) (Perera et al., 2017; Schröer et al., 2015) and graphical user interface (GUI) (D. Park et al., 2020; Yamazaki & Masuda, 2012). In addition, autonomous feeding robots, using vision sensors, are also being actively studied (Candeias et al., 2018; Gallenberger et al., 2019). Moreover, in addition to spoons and forks, tools such as chopsticks and grippers are being used to consider the various types of food. Most of the researchers in Table 2 confirmed the efficiency and effectiveness of the MAR concept developed through user tests, and various numbers of users (1 to 25) participated in each study. Some studies applied new concepts and technologies, considering the positive UX of MARs. For example, Higa et al. (2014) improved portability by putting an MAR in a briefcase. Song and Kim (2012) designed an MAR that allows multimedia viewing on the device display. Yamazaki and Masuda (2012) introduced an MAR, which analyzes the force applied to chopsticks depending on side dishes with different levels of texture.

Table 1. Physical user interface components of commercial meal-assistance robots (Mars).

Commercial robot	Country	Interface	Interchangeability	Tool
Bestic	United States	Physical switch	No	Spoon
Meal Buddy	United States	Physical switch and controller	No	Spoon and fork
Mealtime	United States	Physical switch, pal pad switch, foot adaptive switch	Yes	Spoon and fork
My Spoon	Japan	Joystick, physical switch, joystick with switch	Yes	Spoon and fork
Neater Eater Robotic	United Kingdom	Tablet-based touch interface	No	Spoon and fork
Obi	United States	Physical switch, pal pad switch, micro light switch, pillow switch, sip and puff switch	Yes	Spoon and fork
Winsford Feeder	United States	Rocker switch and chin switch	No	Spoon and pusher

Figure 1. Interfaces of commercial Mars.
(a) Physical switch, (b) Controller, (c) Pal pad switch, (d) Micro light switch, (e) Pillow switch, (f) Sip and puff switch

2.2. Research on evaluation criteria and guidelines

In HRI, the importance of UX evaluations is gradually being emphasized by many researchers (e.g., Kostavelis et al., 2018; Pripfl et al., 2016). UX evaluations in the HRI field should include the quality of the HRI and the robot's behavior and functionality (Lindblom & Andreasson, 2016). According to Dautenhahn (2007), HRI research is divided into three categories: (a) a robot-centered view that uses an autonomous robot, (b) a robot cognition-centered view that solves problems by considering a robot as an intelligent system, and (c) a human-centered view that adapts robot behavior to humans. Alenljung et al. (2017) emphasized that social HRI should be designed, especially in a human-centered view; it is most important to provide a positive UX. Clarkson and Arkin (2007) proposed eight new heuristics in HRI research by using Nielsen's (1994, April) canonical list, HRI guidelines suggested by Scholtz (2002), and elements of the ambient and CSCW (Computer-Supported Cooperative Work) heuristics (Baker et al., 2002; Mankoff et al., 2003). These heuristics focus on usability, such as visibility and flexibility. Weiss et al. (2009) proposed the usability, social acceptance, user experience, and societal impact (USUS) evaluation framework for assessing human-robot collaboration. It differs from Clarkson and Arkin's (2007) research because it proposed a societal impact that considers the effect of robots on the social life of a community beyond the usability of the product. Dautenhahn (2007)proposed four criteria for evaluating robots with social skills among different robot types: contact with humans, robot functionality, role of the robot, and social skill requirements. Compared to other criteria, these are characterized by more focus on the interaction between robots and humans. Breazeal (2004) described nine issues (Comparative media issue, Naturalness issue, User expectation issue, Quality issue, Relationship issue, Teamwork issue, Personality issue, Cultural issue, Acceptance issue) to consider when designing a social robot: 1) the comparative media issue considers the differences when robots are compared to other interactive media (e.g., software agents); 2) the naturalness issue considers natural interaction when users apply the technology; 3) the user expectation issue considers robot capabilities expected by the user, 4) the quality issue considers the development of robots that are helpful and enjoyable to users; 5) the relationship issue considers the relationship between the user and the robot and the social role of the robot; 6) the teamwork issue considers the process to form a team of the user and robot by effective communication and cooperation; 7) the personality issue considers the way in which the user's personality is reflected in the robot design; 8) the cultural issue considers the way in which the user's cultural situation is reflected in the robot design; 9) the acceptance issue considers whether the user accepts the robots.

Social robots have been developed by artificial intelligence and robotics researchers since the early 1990s Social robot, 2021). The social robots started following humans into three different personal settings: home, education, and healthcare

Table 2. Usability studies on Mars with different interfaces and food items.

Study	Interface	Tool	Food item	Usability test
Takahashi and Suzukawa (2006)	Head space pointer	Spoon	-	1 subject
Maheu et al. (2011)	Joystick and switch	-	-	-
Yamazaki and Masuda (2012)	Hands-free pointing device	Chopstick	Diverse Japanese food	-
Song and Kim (2012)	Joystick and switch	Spoon and gripper	Rice and soup	7 subjects
Jardón et al. (2012)	Voice recognition, joystick, and button	Gripper	Drinks	6 subjects
Ohshima et al. (2013)	Touch sensor	Spoon and chopstick	Tofu and pudding	-
Higa et al. (2014)	Switch	Gripper	-	-
Schröer et al. (2015)	BCI	-	Drinks (cup)	6 subjects
Perera et al. (2017)	BCI	Spoon	Solid foods	6 subjects
Admoni and Srinivasa (2017)	Joystick and gaze	Fork	Solid foods	9 subjects
Candeias et al. (2018)	Autonomous	Spoon	Rice and nuts	-
Rhodes and Veloso (2018)	-	Spoon	Rice	-
Gallenberger et al. (2019)	Autonomous	Fork	Small items	25 subjects
D. Park et al. (2020)	GUI	Spoon and fork	-	9 subjects

*BCI: brain computer interface; GUI: graphical user interface environments. An MAR is a type of social robot in healthcare that is intended to provide positive dining experiences while eating and drinking. According to Kumar Shastha et al. (2020), three different types of MARs are presented in the current market depending on their assisting capabilities: (1) the robot can assist with only the eating task, (2) the robot mainly focuses on the eating task, but do provide a function for drinking task, and (3) the robot enables to assist both the eating and drinking tasks. Clarkson and Arkin (2007) suggested physical-user-interface (PUI) design recommendations for MARs and suggested 20 design-related guidelines (e.g., standard height, number of users that can be fed at one time, and appropriate weight). Bhattacharjee et al. (2019) conducted a focus group interview (FGI) and proposed indicators for each technical function, technology robustness, information gap, usability, user empowerment and social acceptance, and system integration. Detailed evaluation indicators were derived through systematic research, but only the aspects of a robot's behavior and functionality were considered; there were few evaluation indicators of the robot's social interaction with users. This study aims to develop evaluation indicators that assess the UX and include the social interaction aspect of MARs.

3. MAR UX survey through FGIs

3.1. Participants

A total of 15 subjects participated in the FGIs. Considering that an FGI generally conducts with three to 10 people in a single group (Preece et al., 2015), there were five subjects in one group throughout the experiment. To collect user experiences from various perspectives related to MARs, groups of patients, doctors, and caregivers were created. None of the subjects have had experience with any MARs.

The mean age of patients was 48 years old (±9.45), and all were male. All patients suffered from cervical spinal cord injuries. All participants in the patient group ate in their private residences with the help of caregivers. The group of doctors belonged to the department of rehabilitation medicine, where spinal cord injury patients are treated; their average age was 40 years old (±2.06) (four males and one female). The average age of the group of caregivers was 58 years old (±8.16) (two males and three females). All were caring for patients with spinal cord injuries and assisting with their meals. This study was conducted with the approval of Institutional Review Board (IRB) (B-1910/568-315) at Seoul National University Bundang Hospital.

3.2. FGI questionnaire

An FGI is a semi-structured interview with both closed- and open-ended questions (Preece et al., 2015). The interviewer conducting an FGI utilizes a standard questionnaire in all interviewee groups and obtains relevant information when deemed necessary for detailed information. In this study, considering the existing studies, such as a framework proposed by Breazeal (2004), a total of five topics were included in the standard questionnaire to collect the UXs of the MAR in terms of social interaction.

The first topic comprised the necessity of an MAR. The questionnaire was set to determine the necessity of three aspects: improving patient independence, reducing care burden, and improving quality of life. The questionnaire was scored on a 10-point scale (0: very low–10: very high). The second topic was the interface, where five participants from each group selected all the interfaces that they believed would be useful when operating an MAR; the options consisted of eight types of interfaces (head, breathing, joystick, physical buttons, eye tracking mouse, voice recognition, electromyogram [EMG], and electroencephalogram [EEG]). The head, breathing, and eye-tracking mouse, which are methods mainly used for the person with tetraplegia, are interfaces where the user finds and selects the desired function through the head movement, breathing, and eye-tracking & blinking. The joystick and physical button are interfaces that use hands. Voice recognition is an interface that has been studied a lot recently, and it can be operated using voice recognition technology. EMG and EEG are state-of-the-art technologies that extract user intentions from biological signals, muscle signals and brain signals, respectively (Zhang et al., 2019). The third topic consisted of questions related to the motion and speed of the robotic arm. Scores related to the usefulness of the robot's three typical arm movements were collected on a 10-point scale (0: very low – 10: very high). The three movements were (a) the movement of the spoon entering the mouth when the mouth is open, (b) the movement of rotation for better ease of eating when using forks or

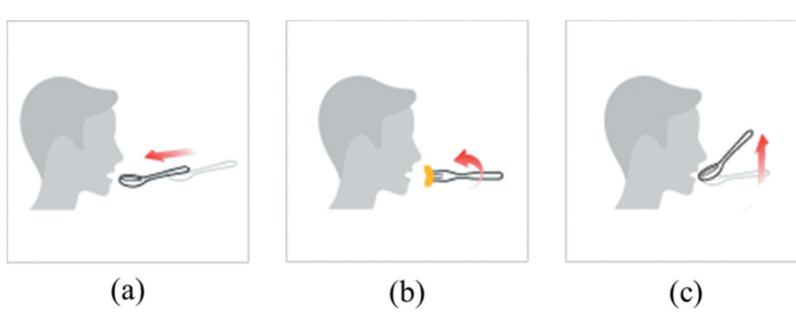

Figure 2. Illustrations of the robotic arm motions.
(a) Motion of reaching the spoon to the mouth, (b) Motion of rotating the utensil in a direction for easier eating, (c) Motion of lifting the spoon

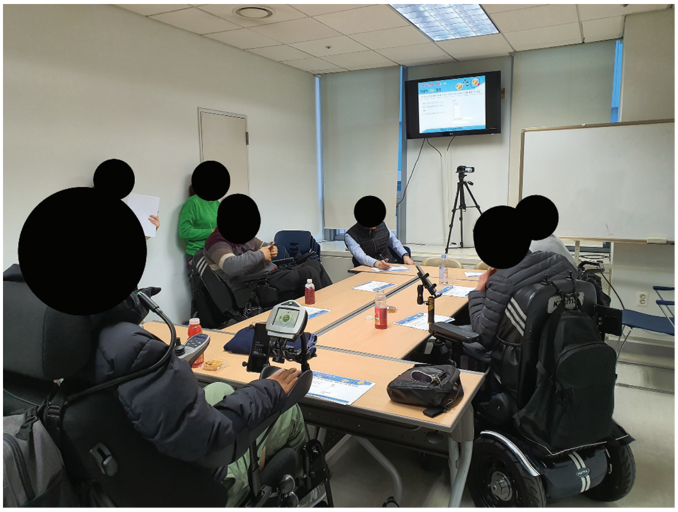

Figure 3. Example of FGI environment for the patient.

chopsticks, and (c) the movement of lifting the spoon after putting the spoon in the mouth and the patient closing his/her mouth (Figure 2). After watching a video of eating food using Obi, a commercial MAR, the speed of the robotic arm was questioned for the time required to select the food and deliver it to the user. The fourth topic involved collecting scores on whether commercially available robots are suitable for Korean meal assistance on a 10-point scale (0: very low – 10: very high). Finally, additional functions of the MARs necessitate were obtained through open discussion, which analyzed the safety and mobility improvements they would need.

3.3. Procedure

In this study, FGIs were conducted for each of the three user groups presented in Section 3.1; a total of three interviews were administered (Figure 3). The interview was conducted in a separate room for each group, and images and videos of MARs and questionnaire items were displayed on the screen installed in the room. Interviewers organized FGIs in the order of the five topics introduced in Section 3.2. Before starting the FGI, to increase the understanding of MARs, we had time to show pictures and videos of various MARs. The participants had time to freely discuss additional opinions along with answers on each topic. Among the participants of the patient group, patients who had difficulty recording the pre-examination questionnaires filled them with the help of caregivers and guardians.

3.4. Results

Quantitative results were analyzed for each group of subjects within the five topics (Table 3). It was confirmed that the interview results for all topics and groups were different. Statistical analysis was performed on the numeric data of the first, third, and fourth topics in Table 3. After checking the normality of the data, the Kruskal-Wallis test was performed to improve independence, quality of life, speed of robotic arm motion, degree of suitability of commercialized robots for Korean meals, and analysis of variance (ANOVA) was performed for other variables. There were statistically significant differences in reducing care burden ($F = 21.41$, $p < .001$) and improving quality of life ($\chi2 = 7.94$, $p = .02$) (Topic #1), speed of robotic arm motion ($\chi^2 = 0.95$, $p = .004$)

Table 3. Analysis of results by the five topics.

Topic	Detailed topic	Unit	Patient group	Doctor group	Caregiver group
#1. Necessity of an MAR	Improving independence	Score	5.8	7.2	7.2
	Reducing care burden	Score	4.4	5.4	9.0
	Improving quality of life	Score	5.8	7.8	9.4
#2. Interface	Useful interface types	Number of choices	Head (3), Breathing (1), Joystick (4), Physical button (3), Eye tracking (2), Voice (0), EMG (0) EEG (2)	Head (3), Breathing (1), Joystick (3), Physical button (2), Eye tracking (4), Voice (4), EMG (2) EEG (3)	Head (0), Breathing (4), Joystick (0), Physical button (0), Eye tracking (4), Voice (5), EMG (0), EEG (0)
#3. Usefulness of robotic arm motion	Motion (a)	Score	6.0	5.2	3.3
	Motion (b)	Score	4.8	7.2	6.2
	Motion (c)	Score	6.8	5.0	4.0
	Speed of robotic arm motion	Seconds	10.0	26.4	20.0
#4. Degree of suitability of commercialized robots for Korean meals	-	Score	4.6	5.8	3.2
#5. Other necessary functions	Safety	-	Notification function for emergency situations	Notification function for emergency situations	Notification function for emergency situations
	Mobility	-	Charging function in wheelchairs, Attaching function to electric wheelchairs	Motion recognition function, Sharing function with other devices, Attachment function to electric wheelchair	Easy assembly and folding of the robotic arm

*Motion (a): motion of the spoon reaching the mouth; Motion (b): Motion of rotation in a direction for easier eating; Motion (c): Motion of lifting the spoon; EMG: electromyogram; EEG: electroencephalogram.

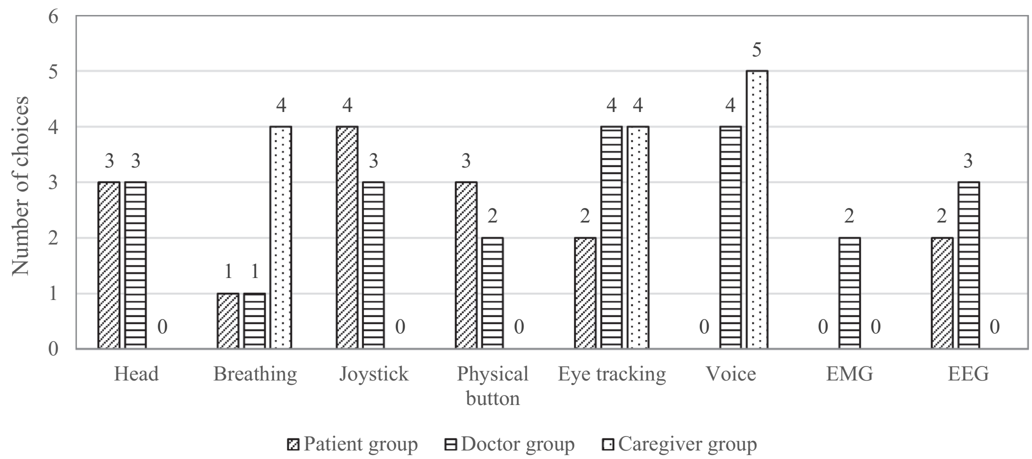

Figure 4. Number of useful interface types selected from each user groups.

(Topic #3), and degree of suitability of commercialized robots for Korean meals (χ^2 = 9.60, p = .008) (Topic #4).

The first topic, the necessity of an MAR, received high scores in the order of caregiver, doctor, and patient for all aspects of independence, care burden, and quality of life. As a result of the Student-Newman-Keuls (SNK) test, the score of reducing care burden was statistically the same for doctors and patients. As a result of the pairwise comparisons, caregiver and doctor were statistically identical in terms of improving quality of life, and doctor and patient were statistically the same.

The second topic, the interface, received different results from all three groups (Figure 4). Joysticks and physical buttons, mainly used in commercially available MARs, were selected by several patients and doctors but were not mentioned by the caregivers. The conversational voice recognition interface, a recently introduced technique, received a high score in the doctor and caregiver groups but not in the patient group. Interfaces mentioned in all three groups included an eye-tracking mouse and breathing. Head and EEG were only mentioned in the patient and doctor groups. EMG was only mentioned in the doctor group.

The third topic, usefulness of robotic arm motion, also received different results from all groups: The patient group scored the usefulness in the order of lifting the spoon (motion c; see Figure 2c), reaching the mouth (motion a; see Figure 2a), rotating the utensile in a direction for easier eating (motion b; see Figure 2b); the doctor group in the order of motion (b), motion (a), and motion (c); and the caregiver group in the order of motion (b), motion (c), and motion (a). As a result of the pairwise comparisons, the speed of robotic arm motion preferred by caregiver and doctor was statistically the same. The patient preferred the speed of robotic arm motion faster than the caregiver and doctor.

The fourth topic, the degree of suitability of commercialized MARs for Korean meals, received low/medium suitability scores from all three groups.

The fifth topic, other necessary functions, received many similar opinions. Regarding safety, all three groups suggested an SOS notification function for emergencies. In terms of mobility, functions such as the charging function, wheelchair attachment function, sharing function between devices, motion recognition function, and assembly and folding functions were suggested. In addition to the predefined questionnaire items in the FGI, unanticipated issues were discussed through the debriefing. In this experiment, opinions about the appropriate weight of the MAR, estimated price, and proper installation time were obtained from the groups through the discussions. Detailed comments, additionally collected through the FGI, are organized by topic in the UX evaluation guideline in Section 4.

4. MAR UX evaluation guideline including social interaction

In this study, guidelines for evaluating UX was proposed, considering the social interaction aspect of MARs. These evaluation issues was revised, and new issues were included based on the characteristics of MARs, by referring to the nine issues presented by Breazeal (2004), that need to be considered when designing HRI, as introduced in Section 2.2. A total of eight UX evaluation guidelines and the evaluation index for each guideline were analyzed based on the FGI results and previous literature (Table 4).

4.1. Usability issue

The usability issue refers to whether the ergonomics and social interaction functions of the MAR are designed to be easy, effective, and efficient for users in the environment in which the MAR is utilized. This is similar to the user expectation issue presented by Breazeal (2004). This is important for intuitive and easy operation so that additional training and manuals are not required. For example, Pourmohammadali (2007) explained the complete tasks (e.g., finding/ picking up the desired food and bringing it to the patient's mouth, and immediately stopping the operation in an emergency) that the MAR must perform in addition to the ergonomic design guidelines (e.g., appropriate size, dimension, mechanical ability, and reachable range) of MARs. Regarding usability, the functions for alarms in cases of emergency, charging functions in wheelchairs, detaching and attaching robots to wheelchairs, motion recognition functions, folding functions of robot

Table 4. Modified UX evaluation guidelines for Mars.

UX heuristics for MAR evaluation	Definition	Evaluation index	Similar issues in Breazeal's (2004) study
Usability	Are the functions of the MAR well designed in terms of ergonomics and social interaction for the MAR expected by users?	Ease of use, Usefulness, Effectiveness, Efficiency	User expectation
Emotion	Is the design of the MAR intended to establish an affective and emotional bond between the MAR and the patient?	Satisfactory voice, Comfortable to use, Enjoyable to use, Satisfying appearance design	Quality
Value	Is the MAR designed to reflect the value it can provide in people's lives	Perceived independence/ convenience, Reduction in time cost	N/A
Naturalness	Is the MAR designed to support eating tasks naturally like an actual human?	Use of language/Gestures, Facial expressions/Vocal accents	Naturalness
Assistance	Do the MAR facilitate efficient and effective meal consumption through collaboration between the MAR and users?	Communication effectiveness, Situation awareness, Reduced workload	Teamwork, Relationship
Acceptance	Do users accept the actions of the MAR positively?	Intention to use. Reasonable price, Technology acceptance	Acceptance
Personality	Is the MAR designed as per the personality of the user?	The existence of custom function	Personality
Culture	Is the function of MAR designed considering the patient's cultural background	The existence of cultural based function	Culture

arms, and so on were obtained through the FGIs. For developing MARs with good usability, factors such as ease of use, usefulness, effectiveness, and efficiency should be considered from the early design and development stage. Rather than simply adding a lot of functions, it is important to be composed of usable functions even with a small number of functions.

4.2. Emotional issue

The emotional issue refers to the degree of emotion and affect within the bond between an MAR and a patient; it is similar to the quality issue (e.g., enjoyable, appealing, engaging) presented by Breazeal (2004). The importance of emotion in UX has been highly emphasized (J. Park et al., 2013). In the case of an MAR, there is a study by McColl and Nejat (2013) that considers emotional satisfaction. The Brian 2.1 robot recognizes a patient's emotional state and can exhibit various facial expressions to communicate naturally. For example, the robot has a function that provides a positive expression during eating activities. The robot also attempts to imitate the emotions mentioned above through various pitches and speeds. Compared with the voice used for neutral expression, the happy voice has a higher pitch and faster speaking speed, and the sad voice has a lower pitch and slow speaking speed. Although the Brian 2.1 is not an MAR, it can provide foundations on emotional recognition and customized responses for other care robots (e.g., PARO robot). The emotional issues are also closely related to the concepts of affect. According to Kim et al. (2016), emotion is an introspective perspective, a neurophysiological state, whereas affect is an image/impression of a product based on emotional fulfillment. Examples of affect include luxuriousness, simplicity, attractiveness, novelty, and so on. To increase the emotional satisfaction of an MAR in the future, it should be designed to consider the aforementioned affects. For example, it is necessary to conduct prior research on which colors, textures or shapes that the target user feels satisfied with, or which frequency and decibel of voice that users feel comfortable. The following comments were collected through the FGIs about emotion and affect while using the MAR.

> (Patient) The reason I want to use a robot is because it is comfortable to use. If people help me, I feel uncomfortable.

> (Doctor) I wish there is a fancy design.

4.3. Value issue

The value issue refers to the amount of value that an MAR can provide in a person's life; it is an evaluation guideline newly added in this study. Values can be considered as goals or means people pursue in their daily lives. According to Park and Han (2013, 2018), commercial products or services can select certain values originally sought by people. In particular, because MAR products are designed for specific purposes, they can achieve the values desired by patients and caregivers.

According to the FGI results obtained in this study, the value satisfaction was found in terms of patient independence and convenience. If the function of moving food to the vicinity of the mouth without spilling it, picking up a water cup, and gripping utensils for ease of eating are implemented, it will be more effective. Even if these functions are not properly implemented, they should at least meet the patient's expected quality. The meal assisting task is the most time-demanding and labor-intensive work by a caregiver. Therefore, overall, the MAR's functions should be executed so that leisurely meals can be consumed without requiring a caregiver. From the perspective of caregivers, such robots are expected to reduce the care burden. The reduction in the care burden can be interpreted as satisfying the value in terms of time cost.

In order to design MAR that satisfies the user value, it is necessary to investigate the values (eg cost, independence, convenience etc.) that the target user considers important and design MAR functions that can satisfy them.

4.4. Naturalness issue

The naturalness issue refers to guidelines for evaluating whether MARs can naturally assist patients/users with meal assistance like actual caregivers. The naturalness of an MAR is a critical design factor for better engagement between the robot and the patient. McColl and Nejat (2013) noted that robots should be designed to be positioned directly toward the user for monitoring meals and providing one-on-one interaction. In addition, it was confirmed that designing a natural HRI by using language and non-verbal communication (gestures, facial expressions, and vocal accents) is achievable because an anthropomorphism function was applied to the MAR, Brian 2.1. For example, to increase the naturalness of the verbal expression, there was a function to greet a person by their name, invite them to sit down, and induce jokes and positive conversations related to or not related to meals. Brian 2.1 was designed to have a human-like physical structure from the waist up; it has two degrees of freedom (DOF) on the waist, allowing the robot to rotate left and right, and tilt back and forth. In addition, the robot's neck has three DOFs for the head movements, such as nods or shakes.

In this study, the types of interfaces for natural interactions between robot and patient were surveyed through the FGIs. As shown in Table 3, it was difficult to determine the most useful interface types between groups of patients, doctors, and caregivers. In addition, it was not easy to make a consensus within the aforementioned groups. Thus, it can be inferred that the criteria for natural interaction are different for each user who utilizes the actual robot, which makes developing a robot that possesses naturalness more difficult. In conclusion, the present study suggests two guidelines to improve the naturalness of an MAR. One is the capability of linguistic interaction function that could increase the friendships between the MAR and the user. The other one is the designing physical structure and shape of an MAR to be similar with a real person.

4.5. Assistance issue

The assistance issue refers to the degree to which the MAR and user can cooperate by considering social interactions, so the patient can more efficiently and effectively consume meals than when assisted by a caregiver. It is similar to the relationship issue and teamwork issue presented by Breazeal (2004). The MAR and user should communicate readily and quickly and the MAR should be well used and trusted by the users through MAR training. You and Robert (2017) presented three types of outcomes to evaluate teamwork: Taskwork (e.g., task completion time and speed, and error rate), teamwork (e.g., communication effectiveness and situation awareness), and subjective outcomes (e.g., workload and attribution). Breazeal et al. (2005) presented teamwork efficiency and robustness as criteria for evaluating human-robot teamwork.

In the FGI results obtained in this study, the following opinions were collected regarding the assistance among the MAR, doctor, and caregiver.

> (Doctor) When one person cares for several patients, a nurse can provide integrated care with a meal assistance robot.

> (Caregiver) If there is a function to manipulate the robot through video call, it will a good function because it can inform the patient about the correct posture of eating, such as You need to straighten your waist.

In MARs, when the everyday feeding activity is in progress, the assistance issue is particularly important. Communication between MARs and multiple users (patients, nurses, doctors, caregivers, etc.) should also be carefully considered when developing the assistant functions. Therefore, in this study, the communication function between the MAR and the patient needs to be considered in designing the MAR, so that the MAR can more effectively assist patients with their meals.

4.6. Acceptance issue

The acceptance issue is an element that assesses the degree to which users (patients) accept MARs' actions. It is necessary to look into what an MAR should not do (causing antipathy) and what an MAR should do, which can be difficult to accept by the user (patient). Since MARs perform tasks that have been performed by caregivers (humans), users are likely to feel isolated if the MARs' behavior is too mechanical (e.g., no social interaction or no humanity). McColl and Nejat (2013) studied the relationship between MARs and the elderly. They proposed anxious attitudes toward the robot, intention to use, perceived ease of use, perceived adaptability, perceived enjoyment, perceived sociability, perceived usefulness, social presence, and trust as evaluation elements of the robot acceptance issue. In addition, Dautenhahn (2007)mentions that as long as a robot's appearance and behavior tend to be like a gadget or device, humans are less likely to identify it as a human-friendly robot. Weir (2018) mentions that people don't make the emotional connection seen in human-robot interactions when they look at a robot as something instead of someone. Furthermore, Hameed et al. (2016) stated in their article that “a strong matching between the humanoid appearance of the robot and its behavior must be achieved” so that people don't feel isolated in their presence. In the absence of this emotional connection, people feel isolated and use them to complete arduous tasks. For example, workers in a car factory treat the robots as a tool to assemble a car.

A person's perception and characteristics directly relate to their acceptance of robots and technology. Older generations with less experience with technology may be hesitant to accept robots in their daily lives. According to Bishop et al. (2019), age, gender, education, and the user's previous experience with technology directly correlate to their acceptance of social robots. Older people tend to experience more anxiety when they're in the presence of a robot. She further states that women are less willing to utilize robots. The mood is an essential aspect of social relationships and plays a vital role in accepting robots. A person experiencing a low mood might find it hard to interact with robots when they want human interaction.

Acceptance can also depend on the previous human-human relationships that a user had. Hameed et al. (2016) found statistics to prove that a person's characteristics affect their acceptance of social robots. An interesting finding from their study was that 90.72% of the people had no previous experience with robots. As a result, a participant's previous experience was considered to be insignificant in this research. However, it was found that people's characteristics play a significant role in their acceptance of MARs.

In the FGIs conducted in this study, the acceptance comments related to "Cost" were collected and considered for further evaluation.

> (Doctor) Users don't want to pay a lot of money to buy a meal assistance robot just to have it feed them instead of a caregiver without any enjoyment or social interaction.

The fundamental human tendency to belong leads to a desire for meaningful and emotional connections with other social beings. Robots can invoke this feeling if they possess natural abilities and invoke human emotions. People tend to prefer robots that provide social interactions in their daily lives rather than a device that does tasks around the house. De Graaf (2016) states that "robots in social environments must engage in social interactions and create relationships to be accepted by society." If users can personify a robot, they are more likely to form unidirectional emotional bonds. Researchers must work with psychological science to achieve this. Once this is achieved, we can expect to see more social interactions with MARs in our society.

Moreover, the demand for social MARs has been increasing significantly. The need for MARs is higher than the demand for industrial robots. According to Fortunati et al. (2015), more social robot units were sold in the last five years than in the previous ten years. It is widely believed that people tend to accept robots that provide enjoyment or social interactions. It is also well known that older populations with fewer social interactions rely primarily on technology for emotional connection. People who belong to these categories will spend more money on robots that provide enjoyment as needed.

The practical MAR design guidelines related to this issue are to identify the different acceptance of user groups (i.e., caregivers, patients, and doctors) and support human-friendly and user-acceptable design components (including appearance, cost), considering user characteristics and expectation.

4.7. Personality issue

The personality issue refers to whether the MAR is designed to reflect the user's personality. In general, matching human-robot personalities facilitates interactions between robots and users, increases positive perceptions of robots, and favors robots more (Robert et al., 2020). For example, if the user has an urgent personality trait, the food delivery speed of the MAR should also be fast; if the user has a leisurely personality trait, the MAR should have smooth movements rather than jerky motions. In addition to matching human-robot personalities, users of a certain nature are expected to prefer MARs over caregivers for meal assistance. In particular, users with introverted personalities would prefer to use MARs to focus on eating alone without interacting with caregivers. In the FGIs conducted for patients, there were also discussions that the use of an MAR does not significantly reduce the needs for caregivers. Still, it can provide a comfort zone in which to feed the food during the desired time of the users, which may be difficult for the caregivers to accommodate. There are limited studies considering the personality of users and robots, but it is believed they will become more common in the future (Robert et al., 2020).

The practical MAR design guidelines for this personality issue are to provide users with customized design components based on the user's personality traits, such as extraversion, agreeableness, openness, conscientiousness, and neuroticism.

4.8. Cultural issue

The cultural issue refers to whether MARs have been designed to function based on the patients' cultural backgrounds. In practice, previous studies have shown that the cultural difference affects acceptance (Bartneck et al., 2005) and likability, engagement, trust, and satisfaction (Li et al., 2010). MARs need to be designed to consider, in particular, table manners, dining etiquette, etc. depending on the culture to which the users belong. In the FGIs conducted, there were many opinions related to the Korean cultural dining styles.

> (Patient) I need chopsticks to eat ramen/kimchi/side dishes, and a function to eat soup.

Previous studies proposed practical guidelines to implement the MARs for the use of chopsticks and spoons. For example, Oka et al. (2020) made a robot arm that could grab items using chopsticks. Their system was composed of a Bestic arm, a mini PC (NUC6i5SYK), a camera (Intel RealSense SR300), an articulated arm with camera attachment (with passive joints), and different kinds of de-attachable multi-grip tools, and different kinds of de-attachable multi-grip tools. They used an algorithm to detect the location of the food on the plate. After they find the location, the coordinates are transmitted to the control system of the Bestic arm. Chepisheva et al. (2016) took a different approach. They tried to replicate the dexterity of the human hand by using a soft robotic hand. The hand is made of soft structures by using anthropomorphic bones, joints, ligaments, and tendons connected to four servo motors. Yamasaki et al. (2012) used two-fingered robots consisting of elastic joints. This robot had two aluminum fingers shaped like chopsticks driven by a DC servomotor (reducer with a reduction ratio of 100 and torque constant of 4.2 (Nm/A)). An elastic body made the joint (phosphor bronze) attached to the thinned section with a strain gauge. They also used a structure to support the elastic body to prevent bending and force the joint. They studied the grasp and transport control of this robot with cylindrical objects that had different rigidities. The experiment results proved to be positive as the mechanism could grasp and transport all the objects successfully. There are mechanical arms and robot arms that represent a human arm that can both mimic chopsticks.

While robots that can use chopsticks are limited, several robots can use a spoon. Some robots are being sold for consumer use. Obi is a robot that is designed to help disabled people feed themselves. It is a robot with one arm, a spoon attached to the end, and four bowls by its base. Once switched on, the caregiver has to guide the arm from the bowl to the mouth. This movement will set the specifications and then lets the user choose from the four bowls containing food. Song and Kim (2012) created a "simple robotic system that has a dual-arm manipulator." They divided its tasks into two parts. One was picking and releasing food, and the other was transferring food to a user's mouth. One arm uses a spoon to move the food from a bowl to the user's mouth, while the second arm moves the food and puts it on the spoon. These are mechanisms that use a simple robotic arm with a spoon attached to its end. However, the software required to manipulate the arms may vary.

The practical MAR design guidelines for this cultural issue are to understand users' cultural backgrounds and provide appropriate design components, such as cooking wares or utensils, to support better usability.

5. Discussion

5.1. Differences in UX based on user group

In general, the caregivers rated the necessity of an MAR highly; however, unexpectedly, patients did not rate the need of an MAR as high as compared to the doctors and caregivers. The MAR received a score of 7.2 points in terms of improving patient independence, 9.0 points for reducing patient care burden, and a high score of 9.4 points for improving the patients' quality of life by the caregivers (Table 3). On the other hand, the necessity of an MAR did not receive a high score from the patient group as compared to the caregiver and doctor groups (improving patient independence: 5.8 points, reducing patient care burden: 4.4 points, and improving quality of life of the patients: 5.8 points). These scores indicate that the caregivers need MARs more than the patients. Moreover, robotic arms' easy assembly and folding function were more important for the caregivers because they need MARs to reduce unnecessary labor. If the robot assists them, they will be willing to accommodate the robot even if the performance drops. However, even though the patients want MARs to eat alone without a caregiver in certain situations, patients gave a relatively low score because they were hesitant to use MARs if the robots operated improperly, impersonally, and anti-socially. Patients may desperately want MARs that maintain functional capabilities, friendships, and social interactions.

The reason for the low score of the patient can be further explained as follows. Unlike other user groups, patients considered a situation where they used the MAR alone without anyone's help. Because patients regarded that this was the purpose of the MAR. However, the level of MARs that have been commercialized so far and MARs that will be developed in the future are at a level that cannot be used without the help of a caregiver. Caregivers should at least prepare food and set the MAR. Consequently, patients expressed their disappointment with the MAR in the FGI. On the other hand, other user groups expressed satisfaction that the MAR relieved some of their labor.

Meanwhile, some aspects were more important to patients than to the other groups, such as the speed of the robotic arm. The patients wanted robotic arms to move more than twice as fast as the doctors and caregivers. In other words, the speed of the robotic arm of Obi meets less than the patient's requirements. Therefore, in this aspect, the usability of Obi seems to be poor. Logically, because the robot's operating speed is directly related to safety, it cannot be increased randomly without safety verification. In this aspect, the current experience of robot users is considered to be lacking. In addition, the patients wanted an integrated design with a wheelchair and were stating requirements directly related to their daily lives. They were interested in sharing the MAR's battery with an electric wheelchair and whether the plate could be easily attached and detached from the wheelchair. In this regard, they also wanted to know whether the controller of the MAR could be shared with that of an electric wheelchair. This was a point that the FGI experimenters hadn't thought of. Therefore, an investigation on patient requirements must be considered.

The doctors' point of view was very different from that of patients and caregivers, so it is worth mentioning. First, they tried to classify patients (e.g., C6, and C7) and think about what the MAR should do according to the type of patient. For example, the presence of swallowing disorders was an important issue for them. If a patient has a swallowing disorder, the spoon's motion should change and MAR or medical staff need to be closely monitored. They thought that patients with severe cervical spine injuries should not use MAR. They valued patient safety and seemed to be conservative. Doctors also believed that MAR's function should be very different depending on whether it was intended to be used for the rest of the patient's life, such as in a nursing home, or as an aid for temporary treatment in a hospital. For example, they didn't think the robot needs to have too many functions for temporary treatment.

The difference between different user groups in terms of UX is that their needs, orientations, and purposes of product use vary. This can be described as a value issue. Value issues act at the back end compared to other UX principles such as usability and emotion. For example, it is important to the patient whether it can be used independently, and to the doctor, the safety and stable management of the patient may be more important to them. Caregivers would like to be relieved of their labor in the short term, but they likewise value patients' quality of life. That is, the terminal effect of the MAR can be explained by what value and how it is satisfied.

To accurately determine this, it is necessary to check the structural equation modeling in future work separately.

5.2. Need for guidelines targeting Mars

In this study, guidelines for the MAR were developed by referring and modifying the HRI guidelines. Because MARs are included in the category of general robots, guidelines widely recognized in the industry can be applied. However, many aspects needed to be modified extensively because there are many types of robots with different purposes. In the case of MARs, the purpose or requirement of use may vary depending on the user group (i.e., patient, caregiver, or doctor). Among the issues in Table 3, usability, assistance, acceptance, and culture issues are important for doctors and caregivers. For patients, every issue is significant, but usability, emotion, and value are essential from the point of view of UX. Thus, guidelines for MARs may need to be developed on an individual basis.

We attempted to provide a new set of guidelines in this study by considering UX and social interaction aspects. As mentioned in the 2.2 section, previous studies focused only on the usability aspect of MARs. This study is further developed from the perspective of social interaction of Breazeal (2004), and is meaningful in that UX elements of usability, emotion, and value aspects are emphasized.

5.3. Preferred interface type

As mentioned in Table 1, most of the interface types used in commercialized MARs are switches, controllers, and joysticks that the user directly manipulates using the body parts. Recently, technology-intensive interfaces such as the BCI and voice are being considered at the research stage (Table 2). In this study, considering this research trends, the interface preferred by the actual user group was checked, and it was confirmed that different types were preferred for each user group (Figure 4).

When all user groups were considered, eye tracking (10) – voice (9) – joystick (7) – breathing (6) – head (6) – physical button (5) – EEG (5) – EMG (2) in that order was highly preferred. Looking at each user group, the patient group preferred the traditional interface: joystick (4), head (3), and physical button (3) the most, and the doctor group preferred the technology-intensive: eye-tracking (4), voice (4), EMG (2), ECG (3) was chosen. In the caregiver group, only specific interfaces such as voice (5), breathing (4), and eye-tracking (4) were selected.

Basically, patients and caregivers are similar and doctors are different. The reason is that doctors focus only on MAR, whereas patients and caregivers usually use other devices, such as electric wheelchairs, in addition to MAR. For patients and caregivers, the concept and stereotype of usability or acceptance of interfaces have been already formed for a long time. Uniquely in the patient group, a voice was never selected, and the following comments were collected:

> (Patient) I think it consumes a lot of energy when talking, and it can be uncomfortable in situations where you are talking with other people.

Depending on the situation, the patient may use MARs alone, or there are cases where MARs are additionally used with a caregiver. Thus, when developing MARs in the future, it is thought that it will be necessary to load various interface types that reflect the preferences of user groups.

5.4. Limitation

In this study, it was important to consider the social interaction aspects of MARs and present the UX evaluation guidelines; however, there are some limitations to the FGI process used for data collection. First, although spinal cord injury patients need meal assistance, opinions from the patients with incurable diseases, such as Lou Gehrig's disease and other groups of users who need meal assistance, such as people with disabilities and older people with low upper body strength, should also be collected. Second, the demographic characteristics of the three groups (caregivers, patients, and doctors) were not diversified. For example, although eating habits and styles may differ between men and women, this study did not collect female patients' opinions. Third, in this study, the FGIs were conducted in one medical institution; it is necessary to collect further data that is more diverse through other medical institutions in the future. Additionally, it is necessary to recruit more subjects. Further research needs to focus on detailed indicators that can be used to evaluate each of the eight guidelines (usability, emotion, value, assistance, acceptance, personality, and cultural issues) and the evaluation index analyzed in this study (Table 4) should be verified from the perspectives of patients and doctors in the future.

6. Conclusion

This study proposed eight UX evaluation guidelines that cater toward MARs, based on the design issues of social robots proposed by Breazeal (2004). FGIs were conducted for the caregiver, patient, and doctor groups, with experience in using MARs, to collect various UX-related information. This study is significant in that the UX evaluation guideline was developed by reflecting the social interaction characteristics of MARs, which have a very high degree of HRI, unlike those features in the previous studies. In addition, it was confirmed that the opinions of all three groups need to be considered when evaluating and designing the UX of MARs in the future by identifying differences in the perspectives of patients, doctors, and caregivers through FGIs. The proposed comprehensive UX guidelines will be particularly useful in the design and evaluation of MARs to improve the social interactions between the robot and user.

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