Designing and Evaluating the Face of Lil'Flo: An Affordable Social Rehabilitation Robot

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***Abstract*— We introduce Lil'Flo, an affordable robot for pediatric upper extremity rehabilitation. We present the design and fabrication methodology of the head and face of the robot, the central design element for emotional expression. Through a guided interview with 10 subjects, a number of faces which have a clear sentiment associated with them are identified. The data suggest that a digital face, characterized by eyes and a mouth, can express sadness, happiness, surprise, and mischievousness well, but that finer emotions, e.g., differentiating between happy and very happy can be difficult. The data fail to show that a robot with a dynamic face is viewed more positively than one with a static face. The results of numerical sentiment analysis and open ended questions provide a design direction for our face and a general idea of simple face designs which have a clear sentiment.**

I. INTRODUCTION

There is a shortage of rehabilitation workers in rural areas and 3rd world countries today [1]. In the coming years, this is expected to get worse, growing to a shortage of 15 million workers globally by 2030 [2]. The United States is already experiencing a shortage in occupational and physical therapists, especially in the south and west of the country [3], [4]. The shortage is due in large part to an increase in demand as a result of aging populations in developed countries [5]. However, it is not only the elderly who will be affected. Other populations who require therapy will also find it more difficult to receive treatment. For example, 2-3 out of every 1000 children born each year have Cerebral Palsy (CP) and require varying degrees of therapy [6].

One option to alleviate some of the supply, demand imbalance is to use robots to supplement the time of clinicians. Classical systems, such as the MIT-Manus [7] are well established as a way to increase therapy time by helping to guide patients through repetitive rehabilitation tasks. Another option with growing prominence are socially assistive robots (SAR) [8]. For pediatric patients with CP, a robot may be able to act as a motivating peer to patients, improving outcomes [9], [10].

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To begin to explore this need, we have worked to develop a low cost socially assistive robot for upper extremity rehabilitation, targeted towards children with non-traumatic brain injuries, such as CP. We chose to develop our own system to have complete flexibility to modify the system and explore the affect of the form and surface of the robot on patient interaction and therapy outcomes. We are also interested in understanding how cheap of a component set can be used when putting together a social rehabilitation robot. We believe that building systems that are low cost increases their translatable impact on the people who need them most.

In order for an SAR to be effective, it must be capable of conveying emotion to patients. Humans convey emotion verbally, through gestures, and through facial expressions [11]. Many robotic platforms exist which can be used as the basis for an SAR. However, those systems are generally not easy to modify, lack expressivity in either their face or body, or are very costly [12]. In this paper, we will focus on the robot face, as the center of emotional communication.

Existing robot faces fill a number of categories. Systems such as the Aldebaran Nao, which is very popular for research and has seen some use in the clinic (for example, as part of the Therapist [13] and Zora [9] projects), have a very static face, with only their eyes changing color. On the opposite end of the spectrum are systems with fully actuated mechanical faces, such as Kismet [14], Milo [15], and KASPAR [16]. In a middle ground are some systems with fully actuated eyes, but not mouths, such as Simon [17] and iCub [18]. There is also a space of robots which eschew mechanical components in favor of digital displays, many of which are surveyed in [19]. These exist from displays with a synthesized human face/avatar [20] to robots with simpler emoticon like displays such as Anki's Cozmo. Some robots, like Tega [21] have a digital display with only eyes. Cozmo uses a digital display with only eyes, but has a camera below them that looks like a static mouth. However, [19] suggests that a mouth can make a system seem more trustworthy and likeable.

One way to look at faces is on a space with extents of realistic and objective (realistic, detailed), iconic and subjective (low detail, realistic), and abstract (not realistic) [16]. The position of a system on this continuum affects how many people can relate to the system and how well it can communicate sentiments. A rehabilitation robot should likely be realistic so that patients can understand it and have a medium amount of detail to allow it to convey a variety of expressions while still being accessible to a wide audience.

In this paper, we will discuss our study of a face which

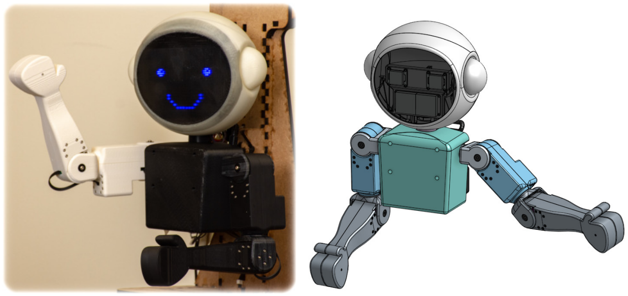


Fig. 1. The upper body of Lil'Flo, our socially assistive robot. Shown on the left is a prototype of the system, on the right is the CAD of the system. Note, color and finish are incomplete.

we have designed for our low cost social rehabilitation robot, Lil'Flo. We will begin by introducing the entire system, then discuss the design and fabrication process for the face, followed by the method and results for testing we did to evaluate our design.

II. Overview of System

In order to make Lil'Flo, a robot which is relevant for upper extremity rehabilitation, we have designed a system with an anthropomorphic form, to allow the system to demonstrate human motion in a natural way (fig. 1). Because we are targeting pediatric patients, it has proportions similar to those of a child through its arms and torso, with a simple head, reminiscent of a toy, giving emphasis to its face. The robot supports shoulder flexion/extension, shoulder adduction/abduction, internal/external rotation, and elbow flexion/extension. It is built using motors from an XYZ Robotics Bolide robot. The Bolide system provides better than hobby grade servos which are digitally controlled with integrated low-level controllers and can provide feedback to the higher level system. These motors were selected because they are cheap, serially controllable servos that can generate enough torque for our system. The shell around the motors is designed to make the robot more aesthetically pleasing and structurally sound. The robot is designed to be mounted onto a mobile base when completed, on which it will appear seated.

The first step in designing the robot was to develop sketches of what the system might look like. Sketches generally fell into the categories of spaceman, toy/doll, and anime (fig. 2). As we continued to refine our ideas, the three major design themes evolved into a spaceman, animal, and child theme (fig. 3). We worked to simplify these ideas, developing primarily with the spaceman theme. We felt that making a generic concept which still had a geometrically interesting form would appeal to the greatest number of people. The color scheme is primarily white, with plans to add small color accents. The goal of the neutral color scheme is to give the system a neutral sentiment and allow the face and motions to drive the emotional state. Our first physical prototype can be seen in fig. 4. The prototype highlighted the importance of having a screen on the face which shows only the eyes and mouth while hiding the internal mechanics and gave direction

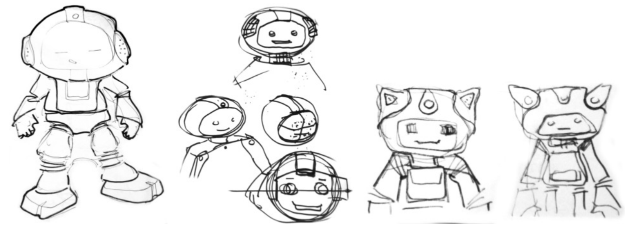


Fig. 2. Early concept sketches for the robot showing a spaceman like concept, a toy/doll concept, and an anime like concept.

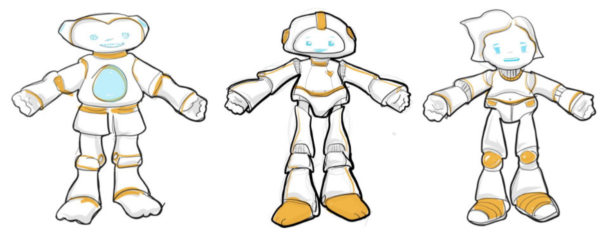


Fig. 3. More refined sketches showing an animal, spaceman, and child theme.

to the correct proportions for the head. The final head design retains the slight curve of the forehead but is rounder.

A large design element on the head is the inclusion of the ear protrusions. During prototyping, an informal straw poll between a head with and without ears showed that the ears were preferred, as they gave a sense that the robot could hear.

A. Face Design Process and Fabrication

For rehabilitation robotics, the goals of being easy to maintain and affordable can make mechanically actuated faces non-desirable. It is difficult to convey emotions with a purely static face. Some systems, like Keepon [22] or R2-D2 are able to use sounds and whole body movements to convey strong emotion, however their ability to convey specificity in their emotions seems limited, prompting our exploration of digital faces. Our system has a face which is designed to be expressive, robust, bright, affordable, and simple. To achieve this, the face uses LED dot matrices. Initially, LCD screens were explored, but it was challenging to get the geometry of the head and face to work with a single large screen while being affordable and having a bright screen. LED matrices solved these challenges. The primary compromises with using LED matrices is that they are single color and have low resolution.

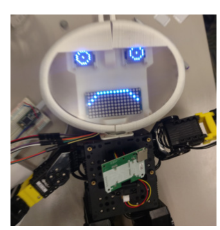


Fig. 4. The first physical prototype of the head for the robot. The head is too wide for the body and the clear screen exposes all of the internal components.

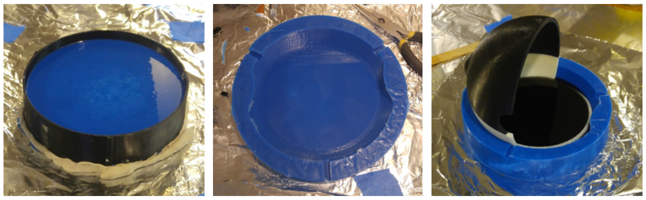


Fig. 5. On the left, making a mold to make the face screen. In the middle, the completed mold for the face screen, which is used to mold the translucent front screen. On the right, the translucent front screen being molded into a 3D printed model of the head. The material being used is a clear urethane with black colorant added.

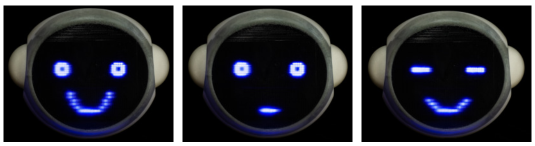


Fig. 6. A few of the eye/mouth combinations chosen for Lil'Flo.

Fig. 7. The experimental setup, showing the head of Lil'Flo, across the table from the subject, a camera facing the subject from the direction of the head, a camera facing the subject and the head from the side, and the interviewer next to the head, with a control computer.

To allow users to see the LED matrices making up the eyes and the mouth without allowing them to see all of the internal mechanical components, a translucent black urethane screen is molded into a thermoplastic 3D printed shell of the head. Molding is used rather than other techniques to allow the screen to have a geometrically interesting shape, with a curved forehead, and to allow the piece to seamlessly exist within the rest of the head. This is done by making a positive of the face and screen together and pouring a mold to match it (fig. 5). This yields a mold which fits the front of the face and defines the shape of the screen (fig. 5). The 3D printed face is then placed into the mold and a clear urethane which has been mixed with a black colorant is added (fig. 5).

Finally, a series of patterns for the LED matrices had to be designed. Eye and mouth proposals were developed, taking inspiration from emoticons and general facial expressions. These were distilled down to mouth/eye combinations which we felt would be most relevant to our use cases (fig. 6 and table I). Some of the eye sets are directional (i.e. able to look left, right, up left, down, center, etc.), others only have a single direction.

III. METHODS

Having designed the face with inspiration from other robots presented in the literature, there were three natural questions about the design. What are users' general feelings towards the head? What emotions/sentiments do subjects attribute to the faces which had been implemented? Is having a face that is dynamic vs. one that is static worth the added costs? In the remainder of this paper we will explore these questions.

A. Experiment Set-up

To test the head alone, we isolated it from the body and presented it to 10 subjects. The subjects were recruited from among the healthy student population. There were 6 females and 4 males and were 20 years old on average. On a Likert scale of 1 to 10 rating familiarity with computers the average response was a 7.9; on rating familiarity with robots the average response was 4.9. Subjects were asked questions about the head while sitting in front of it, by an interviewer (fig. 7). The robot acted in 3 modes: **1)** static mode: showing a neutral smiling face (g in table I), **2)** dynamic mode: cycling through the available faces at random uniformly distributed intervals between 7 and 15 seconds with the eyes changing direction every 3 to 10 seconds, uniformly distributed, **3)** iterate mode: where the interviewer could iterate through all available faces, in random order, changing on key press.

When the subjects initially entered the room, the robot was covered by a black sheet. Subjects were given information on the study and asked to give consent to participate in the study, per the requirements of the Penn IRB. They were asked a series of demographic questions to understand biases in the sample. The head was then uncovered with the face controller set to display the face in either static or dynamic mode (randomly selected) and the subject was asked questions about their opinion of the head design, faces, etc. After a period of time, on command by the interviewer, but without the subject's knowledge, the robot changed mode (static to dynamic or dynamic to static) and the interviewer continued asking questions, including several which matched the function of questions from the pre-switch questions. After all of the questions had been asked, the robot was covered by a black sheet and the subject was asked some general questions about the entire experience. The subjects were then told that they would be shown a number of faces on the robot and should give the first thoughts that they had, the face was placed into iterate mode, uncovered, and all of the faces were iterated through as subjects gave feedback on each one. The face was then covered again and the subjects were asked for any closing thoughts. Subjects were encouraged to give any additional thoughts they might have throughout the interview. The total duration of the interaction was around 15 minutes.

B. Data Analysis

To analyze the data around how the static face compared to the dynamic face, we compared responses to the questions on how friendly the robot seemed, how comfortable subjects felt with the robot, and how machine-like the robot seemed in the static vs. dynamic case. Each of these questions were asked as a pair, once with the face in the static mode and once in the dynamic mode. The data were analyzed using a Wilcoxon signed rank test, within subjects, comparing the responses to questions when the face was in its static mode vs. its dynamic mode. Due to concerns over the lack of a washout period, the data were also analyzed using a Mann-Whitney U-test for each question, comparing between the responses given in the first mode by subjects who first saw the static mode vs subjects who first saw the dynamic mode.

To analyze the subjects' feelings towards each face, the responses were taken and cleaned to condense the set of available words, for example: a response of "god of mischief" was corrected to "mischievous". This has introduced some loss of granularity, for example, the word "sadder" was taken to be "sad", when it is possible that it could have been "mildly sad" or "very sad". Valid responses were culled to only those which were given 3 or more times across all faces by all subjects. The number of times each face received each valid response was summed up. The result can be seen in table I. This method results in some faces which have more than 10 responses, because a subject gave more than one response, for example "sad" and "very sad", and some which have less than 10 responses, because some subjects gave responses which could not be categorized into a valid response.

IV. Results and Discussion

We were unable to show that the robot was viewed as less machine-like in the dynamic mode than in the static mode in either the between subjects ($p = 0.70$) or within subjects ($p = 0.50$) analyses. Similarly, we were unable to show that the robot was viewed as more friendly in the dynamic mode than in the static mode in either the between subjects ($p = 0.64$) or the within subjects ($p = 0.8438$) analyses. We were also unable to show that the robot made subjects more comfortable in the dynamic mode than in the static mode in either the between subjects ($p = 0.11$) or the within subjects ($p = 0.12$) analyses. Plots comparing the two modes between subjects, looking at only the first mode presented, can be seen in fig. 8 and plots of the differences within subjects across the two modes can be seen in fig. 9. No adjustment was made in the within subjects analysis for ordering. One response was excluded from the static mode, machine-like question for being an outlier with potential failure to properly interpret the Likert scale being used, as evidenced by the subject's other responses. One subject failed to answer the question on friendliness of the robot with a numerical value in both modes, and so their data for that question were excluded. A number of other responses are numerically outliers, but appear to be legitimate and so were not excluded.

Some subjects stated that they were ill equipped to answer some questions because they did not know enough about the robot and its function. There was also a sense that the lack of a body in our experiments and flickering lights on the face caused a muted response. Repeating this experiment with the complete robot doing rehabilitation tasks may yield different results.

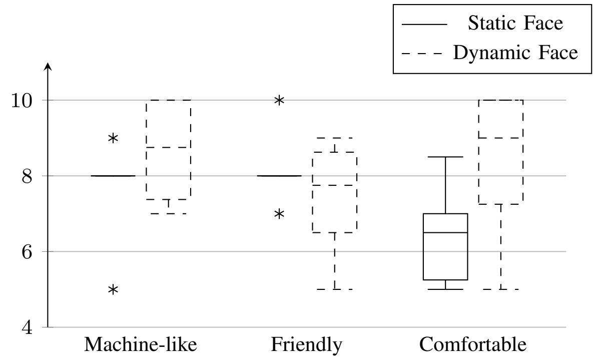


Fig. 8. Ratings on 10 point Likert scales for how friendly the subject felt the robot was (10 is the most friendly), how comfortable the subject felt with the robot (10 is the most comfortable), and how machine-like the subject felt the robot was (10 is pure machine and 1 is pure person). Data are shown for responses from the subjects in the first mode they interacted with the system in. $n_{Friendly_S} = 5$, $n_{Friendly_D} = 4$, $n_{Comfortable_S} = 6$, $n_{Comfortable_D} = 4$, $n_{Machine-like_S} = 5$, and $n_{Machine-like_D} = 4$.

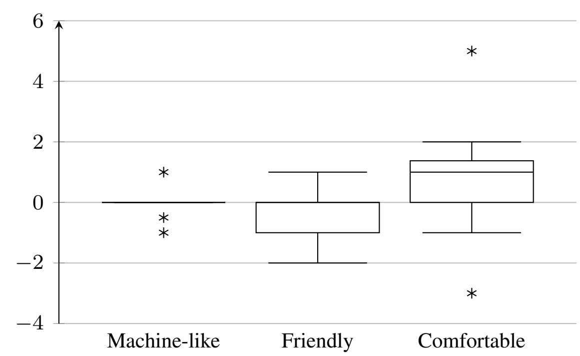
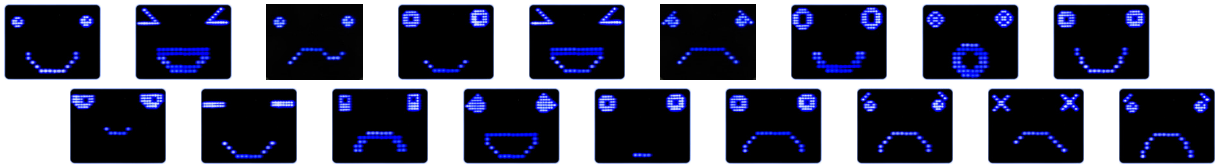


Fig. 9. Differences between static and dynamic modes in ratings on the robot on 10 point Likert scales for how friendly the subject felt the robot was (10 is the most friendly), how comfortable the subject felt with the robot (10 is the most comfortable), and how machine-like the subject felt the robot was (10 is pure machine and 1 is pure person). Data shown is the matched pairs difference of ratings from the dynamic mode - ratings from the static mode for each subject. $n_{Friendly} = 9$, $n_{Comfortable} = 10$, and $n_{Machine-like} = 9$.

As can be seen in table I, the faces M, O, and P have only one sentiment which was associated with them out of the ones shown, although other sentiments were expressed they are not shown due to their low frequency. Faces K, N, and R, all of which are negative, had strong responses for sad, with only small responses for other sentiments. This may indicate that the sentiment sad is easy to convey by this medium. Face A has a good response for happy and the additional responses for neutral make this face a good candidate for the default face on the robot, better than face G, the previous default, but which is seen as equally happy and creepy. Face M could then be used as a non-default happy face. Face B, ranks as both mischievous and smug, which may be useful for rehab interactions containing games, where the robot could, for example, be mischievous in playing a game. Face C rated the highest for excited, with complementary

TABLE I

FREQUENCIES OF PERCEIVED FACE SENTIMENTS REPORTED BY SUBJECTS



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
sad	0	0	0	0	0	4	0	0	0	0	8	4	0	6	0	0	0	9
happy	5	0	2	4	0	0	2	3	2	1	0	0	5	0	0	0	2	0
excited	0	0	4	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0
mischievous	0	5	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
dead	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0
neutral	2	1	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0
creepy	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	3	0
guilty	0	0	0	0	0	0	0	0	0	2	0	2	0	1	0	0	1	0
smug	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
laughing	0	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
scared	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	1
surprised	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
emoji	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
nervous	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0
confused	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0
upset	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0
very sad	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0

sentiments of happy and laughing also shown, making this face also useful for rehab interactions where motivating through excitement can be helpful, for example showing excitement at the success of a patient. Face D was also rated as happy, but not as strongly as faces M and A. Face E received a very spread out distribution of sentiment responses, with no individual sentiment receiving more than 2 ratings. This face was expected to show embarrassment, which it does not. Face F seems to represent the most sad of the faces, with higher rankings for upset and very sad. The data here suggests that a limited face, like the ones shown, can convey gross emotions clearly. To push beyond, into finer levels of emotions, other tools such as robot motion and voice may be necessary. Face H also exhibits this, showing some mixture of more than happy, but varying in sentiment based on the subject. Face I shows a complimentary distribution of excited, happy, and laughing. Although none of these is strong, the combination of them indicates a positive, perhaps jovial sentiment. It is interesting that faces C and I, which are nearly identical have varying responses to laughing. Face J, like faces G and E, has a varied response with conflicting sentiments, making it likely that different patients would view it differently. Face L has the strongest response for scared, but that is heavily confounded with guilty, which is a separate sentiment, making that face unusable. Face Q, like face G, has a large rating of creepy mixed with happy, there are not many instances in a rehabilitation interaction where a creepy robot would seem appropriate.

From the open ended questions during the interview, a number of important points were made. A number of subjects described some of the faces as emoji. Two expressed displeasure over their resemblance, with one subject saying that it made the faces seem non-genuine. Others liked the emoji similarity. The electronics on our system suffer from interference, which causes some flickering in the eyes and face. The subtle flickering was enough that a number of subjects mentioned it as being detrimental to their interaction with the robot. As mentioned prior, subjects generally felt that without a body, they could judge the emotion that the robot was trying to convey, but not accurately say how much they like the robot. When the face started changing for subjects who were initially presented with a static face, several of them noticed and commented on the change. A subject described the face being dynamic as making them be more curious and making the face seem more dynamic. Other subjects said that the face being static vs. dynamic had no impact on their feelings towards it, which follows the result shown in figs. 8 and 9. One subject reported that the playful facial expressions give the robot a living feeling. Commenting on the ears, a subject suggested that they should be more animaloid, like a dog or a rabbit. Other subjects liked the ears. Some subjects found the movement of the eyes to be off putting. This may have been because they were looking around with no pattern and may be another factor which contributed to the results in figs. 8 and 9. The eyes should probably be used to convey the focus of attention for the robot. One subject described the changing face as giving the robot personality. A subject suggested that the face screen be changed from black to white. One subject described the dynamic face sequence as distracting, while another described the static face as creepy.

A. Limitations

The study was performed with a 10 person sample of students from a university, all with technological experience. This is neither a large sample, nor one which represents the target audience for the system. However, we believe that because emotions are a general human expression (smiling is happy, frowning is upset), many of the lessons learned are generalizable. Often styles of facial representation in media produced for children and adults are divergent, but that does not stop one group from understanding the expressions designed for the other. It is worth acknowledging that because our population is disabled and the tangent elderly population has a divergent life experience when compared with young people, those populations might still see some changes.

V. Conclusion

We have presented a new social rehabilitation robot, Lil'Flo, which we are developing. We have explored the functionality of its face, the primary emotional component of the system. Exploring the effect of a dynamic vs. static face showed no significant difference across the metrics of friendliness, comfort, and machine-likeness. The exploration of the face shows some faces which have a clear sentiment associated with them and others which do not, allowing us to select appropriate faces for our system going forward. The sentiments surprised, nervous, and confused, all of which could be useful in rehabilitation interactions are not shown as being well expressed in the current face set, providing an opportunity for future design work. The open ended questions clarify some points to focus our engineering effort on. As we continue to explore the communicative ability of the robot as a whole, there are opportunities for the design of further communication modalities, beyond the face.

The next step for the face is to cull the faces which we have down to a set which clearly communicate emotions and expand that set out to a full emotional palette based on what we have learned. The face also requires engineering work to improve the consistency of the lights. The system will then need to be retested with a mix of subjects from the general population and target population while doing rehab related activities.

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