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An Embodied AI Approach to Individual Differences: Supporting Self-Efficacy in Diabetic Children with an Autonomous Robot

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Abstract. In this paper we discuss how a motivationally autonomous robot, designed using the principles of embodied AI, provides a suitable approach to address individual differences of children interacting with a robot, without having to explicitly modify the system. We do this in the context of two pilot studies using Robin, a robot to support self-confidence in diabetic children.

1 Introduction

In this paper we discuss how a motivationally autonomous robot (named Robin after "Robot Infant"), designed using the principles of embodied AI, provides a suitable approach to address individual differences in the way children interact with it, without having to explicitly modify the system. This robot and the interaction scenario were developed to help diabetic children improve their confidence and skills in managing their own diabetes, by looking after a "diabetic" robot toddler. In [8] we addressed how Robin was designed to support self-efficacy in these children. For developing self-confidence and self-efficacy in real interactions, it is very important that social interaction is appropriate to the interaction profiles and personalities of individual children. Typically, in Human-Robot Interaction (HRI) and Child-Robot Interaction (CRI) individual differences are tackled by personalizing the robot to individual profiles [10]. Personalization is usually done by explicitly tailoring the interactions using methods such as Wizard-of-Oz, by adding references to previous interactions [7], altering the order in which tasks are done [9] or by introducing variables into interaction scripts, e.g. related to personality. However, for our goals of supporting self-efficacy and building self-confidence, a motivationally autonomous robot is more appropriate. It is important that the interaction is unstructured, and partly ambiguous and unpredictable, as this will make the "play" experience feel closer to the complexity of real diabetes self-management. The use of a motivationally and cognitively autonomous robot that can behave and interact as an independent agent is instrumental to this end. As we will see later, it also makes each interaction unique.

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We discuss how we used Robin in two pilot studies with diabetic children in Italy. Although each child was very different in their needs for support for diabetes and the way in which they interacted, we did not need to modify Robin to satisfactorily deal with these differences in both dyadic and triadic interactions.

2 Robin, the Diabetic Autonomous Robot Toddler

In this section we summarize the psychological and clinical basis for the design of Robin, the software architecture, and the interaction scenario. For further details please refer to [8].

2.1 Motivation

Type 1 diabetes is an incurable chronic disease caused by an inability of the body to produce insulin. It is often diagnosed in childhood and, if ill-treated, the high glucose levels lead to devastating complications such as blindness, limb amputations or severe misfunctioning of internal organs. The current treatment involves monitoring and adjusting blood glucose through the provision of insulin – either through a pump or by injection – and glucose – by eating appropriate foods. In order to live independently, an individual with diabetes needs to be able to manage his/her own diabetes (self-management), which in addition to these activities involves being aware of the symptoms of high and low glucose levels, which can vary between individuals, and being aware of how different foods and activities specifically affect their own blood glucose. Diabetes treatment therefore involves a great deal of education, but the ultimate medical aim of this education is behavior change: the acquisition of good diabetes self-management practice.

The concept of *perceived (self-)efficacy* was introduced by Bandura as key element in successfully changing behavior [2]. Synthesizing from the literature, we define perceived self-efficacy as a person's beliefs about their own ability to successfully perform a specific task in a specific situation. Following Bandura's ideas we designed our robot architecture and CRI scenario as a tool to increase perceived self-efficacy in the child, primarily by giving them a *mastery experience* of diabetes management – in this case the child manages the robot's diabetes. It is important that the interaction is unstructured and partly ambiguous and unpredictable, as this will make this "play" experience feel closer to the complexity of real diabetes self-management. The use of a motivationally and cognitively autonomous robot [8, 5] (rather than, e.g., a scripted system) is instrumental to this end, as we will explain in the next section. It also makes each interaction unique, due to both the dynamics of the architecture in interaction with the physical and social environment (the robot never behaves in exactly the same way twice), and to the different ways in which each child treated the robot. Our robot was designed to act like a toddler as we felt that this supported the role of the child as the "carer", it suited the physical appearance of the NAO robot.

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2.2 Robot Architecture

We briefly outline Robin's software architecture, which is described in detail in [8]. Robin's decision-making architecture follows principles of embodied AI [4, 5]. It is built around a "physiology" of homeostatically controlled "survival-related" variables that Robin needs to keep within permissible values. We have also given the robot a simple model of Type 1 diabetes, comprising an internal blood glucose level that increases with "eating" toy food, and decreases with "insulin". Robin chooses how to behave as a function of these internal needs and the stimulation he gets from the environment. Elements of the environment are detected using vision (e.g. foods, faces) and tactile contact (e.g. collisions, strokes, hugs). Internal needs and environmental cues are mathematically combined in what we call *motivations*, which lead Robin to autonomously select behaviors from his repertoire (e.g. walking, looking for a person, eating, resting) that will best satisfy his needs (e.g. social contact, nutrition, resting, playing) in the present circumstances. For this reason it is a *motivationally and cognitively autonomous* robot.

To make it meaningful for our scenario, Robin is not capable of fully attending to all its needs without human assistance. It can play on its own, eat, and, by resting, it can recover from tiredness caused by too much movement. However, it requires assistance from the children to satisfy its social needs (e.g. social presence, strokes, hugs), some of its nutritional needs (the child can "feed" the robot using toy food items), and to control its glucose level.

The children can measure glucose levels and provide insulin to lower glucose (correcting hyper-glycemia) using a Bluetooth glucometer device, or feed the robot high-glucose food to raise glucose (correcting hypo-glycemia). Hypo- and hyper-glycemia have associated symptoms such as tiredness that alert the children of the potential presence of a problem.

Following the initial prototype of Robin described in [8], preliminary tests with non-diabetic Italian children indicated that purely non-verbal behavior was not sufficiently clear to interpret Robin's needs. We therefore added a few simple Italian words (in a recorded "child-like" voice) to indicate hunger, a request for a hug/stroke, and sleepiness. This was in addition to the already present happy and sad sounds, signaling positive and negative changes in its internal state.

2.3 Interaction with Robin

The interactions took place in a "playroom" (Figure 1) decorated to look like the room of a toddler. The majority of the interactions were dyadic interactions between a child and a robot, initially coached by an adult. Robin would be "moving around" (i.e. looking at or walking towards things around the room, trying to eat, exploring, etc.) as the children entered the playroom and they would first interact in the presence of an adult who would show them how to feed Robin, how to use the handheld glucometer to measure glucose and give insulin, explain what toy food items contained a corrective dose of glucose, and encourage them to interact socially. After this initial phase the children would be

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Fig. 1. Robin's playroom at the diabetes summer camp: the environment where the interactions took place. Robin's toys lie around the room; items including food and the glucometer are on a table.

asked if they could look after Robin while the adult left for a short time. All our children were happy to be left alone with the robot. They were provided with a phone that they could use to call an adult for help or to ask them to return. The children were left alone with the robot for approximately 15 minutes, after which the adult would return, and the child could then leave. After the interaction the child would fill in a questionnaire.

The interaction was remotely monitored by the experimenters. In order to ensure each child had an appropriate experience of managing Robin's diabetes, if the robot did not naturally have a hypo- or hyper-glycemia we would remotely set the glucose level high or low. Robin would then act appropriately based on his own internal state, e.g. stopping exploring and resting showing postural and vocal signs of tiredness. The experimenters could also decide to send an adult to the room if a child seemed to be in difficulty and was not phoning for assistance. Since our aim was to improve the children's perceived self-efficacy, we would set the robot's glucose to a normal value towards the end of the interaction so that it did not appear to be in any difficulty when the child left.

3 Trial Interactions

We ran exploratory pilot interactions in order to assess how diabetic children interacted naturally with Robin. Our purpose was to gain insight into how Robin could be used as a tool to support the social and therapeutic needs of different children, rather than a formal investigation of specific research questions. These qualitative observations and analysis, intended to integrate the end-users early in the design of the system, are the object of this paper. We do not present a quantitative analysis at this point.

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3.1 First Pilot: Hospital

We ran a first pilot of Robin with three diabetic children (two girls, one boy) at Ospedale San Raffaele in Milan. All the children had already interacted with a NAO robot running different software, also developed as part of the ALIZ-E project [3], in which the robot and child played a number of educational games related to diabetes, the robot taking the role of either a peer or a teacher. The two robots were referred to as "Nao" and "Robin" to clearly distinguish their different identities. Following feedback from a psychologist, an adult, playing the role of Robin's "engineer", was with Robin in the playroom when the children entered. During the introduction, the engineer explained that he had only recently learned that Robin had "robot diabetes" and he was hoping the child would be able to help him. After the introductions the engineer received a phone call calling him away and he would ask the child to look after Robin until he returned.

3.2 Second Pilot: Summer Camp

We ran a second pilot of Robin at a summer camp for diabetic children in Italy organized by the patients' association SOStegno70[3]. The first tests, like those in the Ospedale, each involved a single child (3 girls aged 10/11, 8 boys aged 11/12). We then ran two tests with pairs of children interacting with Robin (all boys, one of whom had taken part in the single-child interactions). A total of fourteen children, all with Type 1 diabetes, interacted with Robin at the camp. As in the hospital, all the children had previously interacted with "Nao".

These interactions needed to be done in a way that fitted in with the busy timetable at the summer camp. Robin and Nao were introduced to the whole camp as brothers during mealtime presentations. Children who had then put their names on a waiting list to interact with Robin were approached at convenient times during the day and, if they still wished to visit Robin, taken to the room where the playroom had been built. That they were then left alone with Robin was not presented as a "surprise", as it had been in the hospital pilot, and there was no "engineer" character. As some of the children had heard about the interaction with Robin from their peers, we could not be sure what prior knowledge they had when they arrived.

4 Personalized Interactions

In this section, we will discuss individual differences displayed by the children during their interactions with Robin, and how Robin responded to these differences.

Responses to the post-interaction questionnaire indicate that the children found Robin's behavior to be largely coherent and likable. Asked how Robin seemed to them and allowed to choose multiple words from a list – "lovable", "strange", "amusing", "not social" (Italian "sulle sue"), "interested in me", "in

[3] www.sostegno70.org

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difficulty" and "other" – only two of the seventeen children indicated that Robin was "strange" whereas 11 answered "lovable". One child put "other", writing "like a real little boy". Much of the non-verbal behavior of the children seemed to corroborate these results, for example there were several occurrences of the children spontaneously imitating the robot – a number of them clapped when Robin clapped his hands, or imitated his vocalizations. This imitation included unobtrusive mimicry, which is linked to empathy and positive social interaction [6]. In addition, all the children appeared to be fully engaged in the interaction, and none showed signs of wanting to leave before they were interrupted by the returning adult. Robin was perceived and treated in this way despite the fact that children interacted with him in very different ways – each child was a world of his/her own. This shows that Robin was successful in coping with individual differences.

In the remainder of this section we discuss some of these individual differences grouped in terms of some relevant interaction criteria.

4.1 Socially proactive vs. socially responsive

All the children were responsive to Robin's vocalized requests for food, drink and hugs. These vocalized requests were Robin's most clearly expressed prompts for the children to interact. All the children also helped Robin to stand and responded when he expressed tiredness, although to differing extents. In the post-interaction questionnaire all the children answered the question "Was it easy to guess Robin's needs and desires?" with "yes" or "sometimes".

However, outside of Robin's requests, we saw different interaction patterns. Some children interacted with the robot almost continuously, for example taking it upon themselves to "entertain" him with toys, responding to Robin's hand claps by clapping their own hands, or by walking alongside him. At some points some children took this even further, dominating Robin's attention, for example by turning him towards them if he turned away, or physically carrying him to another part of the playroom. In contrast to this, other children allowed Robin to do as he pleased, exploring the room and interacting with what he came across there. These latter children should not be thought of as "not interacting" as they still responded to the vocalized requests and falls as noted above.

One particular child who acted in this "responsive" way was a boy who gave the impression that he was "cool" or streetwise. At one moment during the interaction, he played football with the toy duck that was in the room, seemingly distracted. However, he perfectly understood, and was quick to respond to, every single one of Robin's vocalized requests (in the post-interaction questionnaire he indicated that he found it easy to guess Robin's needs and desires, although he was one of only two children to indicate that he found Robin "strange"). He did not respond immediately to Robin's expression of tiredness; however, when Robin continued to express tiredness, he phoned for assistance and used the glucometer as instructed before feeding the robot. Even though aspects of his behavior may have given the impression of being distracted, he gave many indications of engagement with Robin. For example, after testing Robin's glucose

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later in the interaction and finding it was now back in the normal range he made a small gesture as though in triumph. On a number of occasions he appeared to imitate Robin: raising his hand to apparently mirror an action by Robin, or clapping his hands immediately after Robin had done so. In addition to these, and possibly indicative of how the child viewed his own and Robin's diabetes, he also examined his own glucose pump in a way that seemed connected with his interaction with Robin. For example, when he had checked Robin's glucose for the first time and fed him to correct the hypoglycemia he briefly looked at his own glucose pump; some time later he looked at his pump, and as though reminded by this he then immediately checked the robot's glucose. A similar pattern of checking his own pump in parallel with Robin's glucose level appeared to persist to the end of the interaction. Although we should be careful about reading too much into this anecdotal observation, it is suggestive and perhaps of relevance both in terms of how the child viewed the robot with respect to himself and the child's awareness of diabetes.

Because Robin's motivations for acting depend on both his internal needs and external stimuli (which include different varying cues from the children), he could respond differently and appropriately to this variety in social interaction style. Detecting a face, which occurred more frequently with socially proactive children, would increase Robin's motivation for social interaction, often causing him to open his arms towards the person – a gesture inviting a hug. On the other hand, over periods without social interaction, more frequent in the "responsive" style, the robot's social need would increase, eventually becoming dominant, at which point the robot would vocalize this need, attracting the child's attention.

4.2 Verbal vs. non-verbal

Robin used only single words to indicate his motivations, and made affective vocal noises to express pleasure or displeasure. However, the children showed different degrees and types of verbal behavior when left alone with Robin.

For example, one girl, who in the briefing session said that Robin reminded her of a young cousin, talked a great deal to Robin as she was interacting with him, for example talking encouragingly to him as she tried to feed him an apple. Alongside this, she showed very proactive non-verbal behavior, such as moving Robin about the room. Another girl who also talked a great deal and encouragingly, did so with a different social manner, seeming to respect Robin's autonomy and giving him space, even going so far as to ask Robin if he wanted her to help him stand as she watched him struggle to get up after repeatedly falling.

Many of the children did not speak very much to Robin, though several of them would call his name in a variety of tones, and many said "Ciao" as they left the playroom. This was in contrast to the interactions with Nao in which the robot spoke with some fluency (using Wizard-of-Oz) and games such as the diabetes quiz were built around vocal interaction. Our presentation of Robin as a toddler with very limited verbal ability was viewed as coherent by all the children, and supported the different ways they wanted to interact with him along the verbal–non-verbal spectrum.

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4.3 Response to diabetes symptoms

There was a range of responses to Robin's diabetes symptoms, perhaps reflecting the range in the children's own confidence and knowledge. We will briefly describe examples at the two ends of the spectrum.

One boy, aged 9, as the adult was about to feed Robin during the introductory phase, spontaneously prompted the adult to check Robin's glucose levels. This showed high awareness of diabetes management and indeed the boy checked Robin's glucose levels several times during the interaction, including after Robin had fallen (hypoglycemia can cause people to become dizzy or to faint). After seeing the adult move the high-glucose food items away from Robin during the introduction, the child also hid them behind the table during the interaction. Even before he left Robin with the adult at the end of the interaction he made sure these food items were well hidden behind two of the larger toys.

One girl, aged 10, and who had been diagnosed with Type 1 diabetes for only one year, appeared to show very little awareness of correct medical response to diabetes symptoms. When alone with Robin, her response to his tiredness due to hypoglycemia was purely affective. She offered comfort – gently stroking his head – but did not use the glucometer. On this occasion the experimenters, who were monitoring the interaction, took the decision to send the adult back to the interaction room. On finding out what the situation was, he asked if she had checked Robin's blood glucose. She then took the glucometer from the table and used it to measure his glucose. Then, with a small amount of encouragement from the adult, she fed Robin a corrective dose of glucose. Robin quickly recovered and started walking around again. The interaction finished a few minutes later with hugs between Robin and the child. Since she was relatively inexperienced in diabetes management, it is not too surprising that she did not use the glucometer until prompted. However, diagnosing and treating the hypoglycemia with the adult still provided her with a mastery experience, albeit a directed one, and the system was flexible enough to allow for this. In contrast to her observed behavior, in her questionnaire response she rated the game as "very easy" and she didn't want an adult present to help with difficult situations. She did, however, indicate that the teaching games that she had played with the other robot had helped her with Robin, specifically that before eating it was necessary to check the glycemia.

4.4 Interactions with two children

In order to test the flexibility and scalability of Robin, we also ran two interactions using exactly the same system and scenario, but with two children (boys) interacting with him at the same time. In the first trial one child was new to Robin, while the other had already interacted with him on his own; in the second, both children were interacting with Robin for the first time. On both occasions, we observed some examples of the children working as a team – for example by passing the glucometer for the other to use when Robin indicated he was hungry, or the bottle of water when Robin indicated he was thirsty. In contrast to this

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teamwork, on other occasions the pairs could be viewed as behaving in a more competitive manner, for example by simultaneously trying to attract Robin's attention with toys or food, or by putting themselves in Robin's path.

Two children with different familiarity. The boy who had previously interacted with Robin had not, during that first interaction, seemed confident about his ability to manage Robin's diabetes: as soon as Robin indicated he was tired, the boy had phoned for advice and confirmation about the exact procedure to follow. However, on the second interaction he entered the playroom with a happy "Ciao, Robin!" and stroked his head. He then attempted to feed Robin some apple, although Robin was not motivated to eat at that point. Then, when the adult was giving a shortened introduction to Robin, the familiar child (we will refer to the two boys as "familiar" and "new") initiated the discussion of the glucometer, showing the new boy how to use it. When the new child was being told about the food items used for correcting hypoglycemia the familiar child volunteered his own contributions. When the two were working as a team, the familiar child took the leading role, for example by initiating the use of the glucometer by passing it to the new child. At the end of the interaction, when the adult returned, the familiar boy measured Robin's glucose and reported it to her, with apparent pride. This increased confidence is consistent with our design of Robin as a tool for increasing perceived self-efficacy – although increased perceived efficacy in managing Robin's diabetes does not necessarily mean that he was more confident in his abilities to learn to manage his own diabetes.

Two children new to the interaction. This group showed a lot of exploratory behavior, which we hadn't seen in other interactions. For example, when one of the more ambiguous situations occurred: Robin became tired for reasons unrelated to his diabetes. At this point, after measuring his glucose and finding it in the normal range, the two boys discussed what to do. They (correctly) gave no treatment on this occasion, but continued to monitor Robin's glucose. Another novel way of interacting occurred when one of the boys arranged the soft toys to form three sides of a square and lay Robin down inside the square with his head resting on one of the banks of toys, as if making a bed for Robin.

5 Conclusions and future work

In this paper we have discussed the use of Robin, a motivationally autonomous robot designed using embodied AI principles, as a suitable approach to deal with individual differences in CRI. We have illustrated this with observations from pilot studies carried out with seventeen diabetic children in Italy.

Already this basic implementation of a motivationally and cognitively autonomous robot, with no explicit adaptation or learning capabilities, can deal with a wide range of significant individual differences, without having to modify the system. Based on this experience, we would like to put forward the embodied AI approach to autonomous robots, currently little known and under-used in

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HRI and CRI, as a very promising avenue for dealing with individual differences in these fields.

In addition to this, this approach can also address personalization in a natural way as part of the interaction. For example, we have already started investigating the inclusion of explicit behavior adaptation techniques, such as imitation of specific non-verbal behavior for each child as a way of promoting positive bonds [1]. We have also started to explore the adaptation of the level of social responsiveness to that of the child as a function of the input received in the interaction.

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