Design and evaluation of a personal robot playing a self-management education game with children with diabetes type 1

Blanson Henkemans, Olivier A.; Bierman, Bert P.B.; Janssen, Joris; Looije, Rosemarijn; Neerincx, Mark A.; van Dooren, Marierose M.M.; de Vries, Jitske L.E.; van der Burg, Gert Jan; Huisman, Sasja D.

DOI
10.1016/j.ijhcs.2017.06.001

Publication date
2017

Document Version
Accepted author manuscript

Published in
International Journal of Human-Computer Studies

Design and evaluation of a personal robot playing a self-management education game with children with diabetes type 1

Olivier A. Blanson Henkemans, Bert P.B. Bierman, Joris Janssen, Rosemarijn Looije, Mark A. Neerincx, TNO, Leiden, the Netherlands

Marierose M.M. van Dooren, TU Delft

Jitske L.E. de Vries, Rutgers

Gert Jan van der Burg, Ziekenhuis Gelderse Vallei

Sasja D. Huisman, LUMC

Corresponding author

Olivier A. Blanson Henkemans

TNO Lifestyle, Leiden, the Netherlands

Schipholweg 77-89 2316 ZL Leiden, the Netherlands, E: Olivier.BlansonHenkemans@TNO.nl, T: +31(0)888 666 186, F: +31(0)71 51 81 918

Abstract

Objective

To assess the effects of a personal robot, providing diabetes self-management education in a clinical setting on the pleasure, engagement and motivation to play a diabetes quiz of children (7-12) with type 1 diabetes mellitus (T1DM), and on their acquisition of knowledge about their illness.

Methods

Children with T1DM (N=27) participated in a randomized controlled trial (RCT) in which they played a diabetes mellitus self-management education (DMSE) game, namely a diabetes quiz, with a personal or neutral robot on three occasions at the clinic, or were allocated to a control group (care as usual). Personalised robot behaviour was based on the self-determination theory (SDT), focusing on the children's needs for competence, relatedness and autonomy. The SDT determinants pleasure, motivation and diabetes knowledge were measured. Child-robot interaction was observed, including level of engagement.

Results

Results showed an increase in diabetes knowledge in children allocated to the robot groups and not in those allocated to the control group (P=.001). After three sessions, children working with the personal robot scored higher for determinants of SDT than children with the neutral robot (P=.02). They also found the robot to be more pleasurable (P=.04), they answered more quiz questions correctly (P=.02), and were more motivated to play a fourth time (P=.03). The analysis of audio/video recordings

showed that in regard to engagement, children with the personal robot were more attentive to the robot, more social, and more positive ($P<.05$).

Conclusion

The study showed how a personal robot that plays DMSE games and applies STD based strategies (i.e., provides constructive feedback, acknowledges feelings and moods, encourages competition and builds a rapport) can help to improve health literacy in children in an pleasurable, engaging and motivating way. Using a robot in health care could contribute to self-management in children with a chronic disease and help them to cope with their illness.

1. Introduction

1.1. Self-management in childhood type 1 diabetes mellitus

The growing burden of chronic illness has led to an increasing focus on self-management in health care. This also applies to the increasing number of children with a chronic illness (WHO, 2010). For example, the incidence of childhood type 1 diabetes mellitus (T1DM) is rising rapidly, with a doubling time of less than 20 years (Patterson et al., 2009). T1DM is associated with serious short and long term complications, such as hypoglycaemia, nerve damage and micro- and macrovascular damage. These complications cause high morbidity and mortality, affect quality of life, and push up health-care costs. Complications can be reduced with optimal self-management (American Diabetes Association, 2003).

Children aged 7-12 with T1DM are encouraged to get involved in their diabetes management in order to minimise the impact of their illness on their short- and long-term health (Dedding, 2009). Diabetes self-management is positively associated with metabolic control and health-related quality of life (Hood et al., 2009; Levine et al., 2001; Lynne et al., 2002; Hoey et al., 2001; Kalyva et al., 2011; Wagner et al., 2005). It consists of (1) monitoring carbohydrate intake, physical activity and blood glucose, (2) recognising and mitigating symptoms of hypo- and hyperglycaemia, and (3) administering insulin to regulate blood glucose levels accordingly. In pre-adolescent children, parents play a prominent role in diabetes self-management. As children move towards autonomy during puberty, it is important that they become more skilled at self-management at an early age, albeit in line with their emotional, cognitive and physical skills (Blanson Henkemans et al., 2012; Scott, 2013).

1.2. Games for diabetes self-management education

Knowledge plays an important role in children's diabetes self-management. Enhanced knowledge can contribute to more effective management, better adherence, and improved HbA1c (Couch et al., 2008; Roper et al., 2009). It is advised to provide self-management education for the treatment and prevention of hypoglycaemia, acute illnesses, and exercise-related blood glucose problems (American Diabetes Association, 2003; Qayyum et al., 2010).

Knowledge can be enhanced through Diabetes Self-Management Education (DSME) covering topics, such as blood glucose monitoring, insulin replacement, diet, exercise, and problem-solving strategies (Couch et al., 2008). Qayyum et al. (2010), for example, evaluated the effect of DSME on glycaemic control (HbA1c) in children suffering from T1DM. Those children were educated in two sessions, during which general information was provided about the disease, basic insulin therapy, planning for hypo- and hyperglycaemia, activity, travelling and basic nutritional management. A significant improvement was found in glycaemic control (in other words, HbA1c levels were found to be lower) in children who completed the DSME programme.

Various studies have shown the benefits of gaming for DSME. In their literature review, DeShazo et al. (2010) identified research on diabetes education video games, reviewed themes in diabetes video game design and evaluation, and evaluated their potential role in diabetes self-management education. The authors found multiple video game interventions for T1DM on different platforms (PCs, smart phones and consoles), including quizzing, skill training and decision-making. Themes included self-monitoring, blood glucose, diet and exercise, and medical adherence. Overall, these games had a positive impact on knowledge and self-efficacy, disease management adherence and glycaemic control (hyperglycaemia and HbA1c). Notably, the authors also established that few of the reviewed video games were tailored to a diverse population with varied educational backgrounds and goals. This represents a missed opportunity, since personalisation, or “tailoring”, can considerably contribute to the motivation to continue playing games and therefore to improve playing skills and knowledge (for example, Baranowski et al., 2008).

1.3. Personalised and long-term child-robot interaction

The European 7th framework (FP7) project ALIZ-E has been looking at how personal robots can help children to cope with their chronic disease and to improve self-management through adaptive and long-term educational interaction (www.aliz-e.org). The ALIZ-e project used the Nao, an autonomous, programmable humanoid robot from Aldebaran Robotics. Details on the interaction and activities between the child and Nao robot, the use of a “Wizard-of-Oz setup (i.e., the robot was partially operated by the experiment leader), system modules and architecture are further discussed in in Blanson Henkemans et al. (2013).

Multiple other studies explored the benefits of personal robots for educating children. They show that personalisation has additional benefits for Child-Robot Interaction (CRI), regarding engagement, pleasure, fulfilling social needs and motivation. Also, personalisation proved to enhance the effects of CRI on developing math skills and increasing health awareness (e.g., Janssen et al. 2011; Van Der Drift et al., 2014, Tielman et al., 2014). These studies also showed a number of needs for further research on benefits of personal robots for educating children. First, these studies did not look at the effect of a personal, motivating robot for the development of knowledge required for self-management, in a clinical setting. Second, these studies looked at CRI on one occasion or a maximum of three occasions over a period of three weeks. It is unclear how the interaction is evaluated over a longer period of time. Finally, they lack a strong theory-based underpinning, such as the use of self-determination theory, for the intervention by the personalised robot.

Other research looks at the use of robots for individuals with Autism Spectrum Disorders (ASD). Illustratively, a literature review from Diehl et al (2012) looks at different categories of robot research in this population. These categories are amongst others the use of robots to elicit behaviours (for example, promote prosocial behaviour), the use of robots to teach and practice a skill (for example, initiating a conversation), and the use of robots to provide feedback on performance (for example, positive reinforcement when performing social behaviour). Their results showed notably that most studies are exploratory and have methodological limitations. Based on these studies, it is difficult to draw firm conclusions about the clinical utility of robots in children with ASD.

Considering the benefits of a personal motivating robot discussed in the literature and need for further research on the effect of personalisation in CRI in a clinical setting over a prolonged period, with a strong theoretical underpinning, on developing diabetes self-management knowledge, a pilot study was conducted. It tested a robot applying personalised behaviour, based on the self-determination theory, and playing a DSME quiz (Blanson Henkemans et al, 2013). Five children aged 8-12 participated in the study located at the Wilhelmina Children's Hospital (WKZ) in the Netherlands. The results of pre-post testing showed that diabetes knowledge was enhanced. In addition, the children said the robot and quiz were pleasurable, but this appreciation declined over time. The children looked more at the personal robot than the neutral robot and spoke to it more.

The outcomes of this pilot resulted in a study, described in the current paper. Children aged 7-14 with T1DM interacted with a personal or neutral robot at a diabetes clinic or were assigned to a control group (care as usual). As in the pilot, the aim was to establish an empirical basis for 1) a “learning by playing with a robot” approach over a prolonged period, and 2) the effects of personalisation on child-robot interaction in a clinical setting. Results could provide a considerable step in the further development of social robots, as studied in the ALIZ-E project.

2. Design of personal robot playing a diabetes game

2.1. Quiz to learn about diabetes

In this study, the child and robot played a diabetes quiz. They took turns in asking multiple-choice questions about diabetes (for example, “What do you do for your diabetes before performing sports” and “How do you recognise a hyper?”) and topics of interests for children (such as “On what side of the road do they drive in Thailand?”).

The child and the robot played three quiz sessions , one every six weeks. One session counted multiple quiz rounds, to a maximum of six. During one round, the child and robot both asked and answered two questions, of which one was about diabetes. After rounds three, four, five and six, the robot asked the child whether he or she wanted to play another round or to end the game. Thus, during each session, it was possible for the child and the robot to answer a total of twelve questions each, of which six were about diabetes. Within both categories of quiz questions (general and diabetes), the questions were fully randomized, although a quiz question was only posed once per session. As such, each question could be posed by the natural robot, the personal robot or the child. With this approach, we aimed at minimizing the impact of possible variance in the difficulty level of the questions on the children motivation and knowledge level.

The child and the robot shared a monitor (tablet PC). It displayed the quiz question, multiple-choice answers and the scores of both the robot and the child. The monitor was placed on a seesaw-like device, allowing the monitor to be flipped after every turn (Figure 1). The robot was programmed to sometimes answer incorrectly or make a random guess. The robot could randomly answer the question right or wrong with overall a ratio 4 to 1. This ratio is based on experiences from the pilot study, in which the children also answered the questions correct and incorrect with an average ratio of 4 to 1 (Blanson Henkemans et al., 2013). If either the child or robot answered a question correctly, they received a point. At the end of a session, the one with the most points at the end won the game. This motivated children to continue to play, e.g., if a child lost from the robot, he/she was motivated to win next time.

The pilot study previously conducted provided a suggestion for improvement of the quiz (Blanson Henkemans et al., 2013), which we addressed during preparations for the current study. The children thought the robot and quiz were pleasurable and motivating, but disliked the repetition in the quiz questions. To address this issue, we enlarged the database of quiz questions by inviting 60 children aged 8-12 in a school environment to think of quiz questions they liked. We also asked the diabetes nurses from the Gelderse Vallei Hospital to develop additional questions on diabetes self-management. The result was a total of 150 questions in the game, 32 of which were about diabetes.

2.2. Self-determination theory for personalised robot behaviour

Personalised robot behaviour was based on the Self-Determination Theory (SDT), which arguments that: 1) intrinsic motivation is the core type of motivation in the context of play; 2) *autonomy, competence* and *relatedness* are psychological needs, which relate to intrinsic motivation, in this context (Ryan et al., 2006; Frederick et al., 1995; Pryzbylski et al., 2010). Autonomy refers to 'the sense of volition or willingness when doing a task' (Deci et al., 2000). Competence refers to 'the need for a challenge and the feeling of effectance' (Deci, 1975). Relatedness refers to 'when a person feels connected with others' (Ryan & Deci, 2001).

Specific strategies can be applied to enhance each of these needs (Niemiec & Ryan, 2009). Strategies for enhancing autonomy include providing choice and meaningful rationales for learning activities, acknowledging children's' feelings about those topics, and minimising pressure and control. These strategies were incorporated as follows. The personal robot encouraged the children during the quiz, to think of activities for self-managing their diabetes in personally relevant situations (for example: "You're playing your favourite sport 'football' and need to urinate frequently. What should you do?"). Furthermore, the robot let the children choose whether to play another round, putting the children in charge ("Do you want to play another round?"). In addition, the robot acknowledged the child's mood (for example, excited, glad, bored, frustrated) and then asked whether the child wanted to continue playing ("I see you are a bit bored. Do you still want to play one more round?").

Strategies for enhancing competence include providing effectance-relevant, as opposed to norm-based evaluative, feedback and optimally challenging tasks. To further a sense of competence, the personal robot provided positive comments and reinforcement. At the end of each quiz round, the robot asked the children their opinion on the game (discussing topics such as pleasure level, level of difficulty, and expectations about winning or losing). The personal robot provided feedback on the child's performance and encouraged competition. For example, when the child was ahead of the robot in points, it said: "You're winning, but I will do my best to catch up!" When the child was behind it provided motivation by explaining that there was still a chance to catch up if the child played well and the robot stated it was convinced the child had it in him or her. The robot for example said: "You are behind in points. You are a good player and I believe you can catch up." The robot provided comments on the child's answer, taking into consideration the child answer to the question (right or wrong) in the previous session. For example, if the child answered a question correctly in the second session after getting it wrong in the first session, the robot responded to this by saying things like “Last time you did not know the answer to this question, but now you do. You really are getting better at this quiz!”.

Strategies for enhancing relatedness include conveying a personal, positive and respectful approach and respect for the children. The expectation is that responding to these needs will increase the motivation to play a game or at least maintain it at a high level. The personal robot used the child’s name during the interaction, adjusted the colour of its eyes to the child’s favourite colour. The children could also put personal questions to the personal robot at all the sessions before the quiz started. For example, the child could ask the robot about its age, background, and favourite sports. Since both the robot and the child put questions to each other, they got to know more about each other (See Table 1 for a case study of a child interacting with both robots).

2.3. Research question

The research question we wished to answer was: "How can a personal robot, which applies strategies enhancing autonomy, competence and relatedness, contribute to children’s perceived pleasure and engagement with, and motivation for, learning about diabetes and to their knowledge of diabetes?”

3. Evaluation

For this study we designed a personal robot playing a DSME quiz. We hypothesised that playing multiple DSME quizzes with a robot contributes to self-management knowledge in children with T1DM. Also, we hypothesised that a robot applying strategies derived from SDT contributes to ongoing pleasure and motivation to play a DSME quiz.

3.1. Participants

The participants were children (girls and boys) aged 7-14 with a diagnosis of T1DM dating back at least six months. Participants were recruited through the paediatric department of the Gelderse Vallei Hospital in Ede (Netherlands). The study protocol was approved by the ethics committee of the Gelderse Vallei. Parents and children received a letter with information about the study (goal, results, contribution to ALIZ-e project, data processing and rights) and an invitation to participate in the study. Parents gave written informed consent for participation of their children in the study and the children provided verbal assent and an initialled consent form. A total of 45 children and their parents were invited to participate in this study.

3.2. Study design

A between-subject design was applied (Figure 2). Parents and children gave informed consent and completed a questionnaire, relating to demographics and medical background of the child. The children were allocated to the personal robot, neutral robot or control group (care as usual). The study was conducted in three sessions at intervals six weeks. The first and last session took place at the outpatient clinic as part of the regular check-up, during which the child also met the diabetes paediatrician, nurse, dietician and psychologist. The children made an extra visit to the hospital for the second session. This session also took place at the outpatient clinic, but was not part of the regular check-up.

The children assigned to the personal or neutral robot groups played with the robot at the clinic, in one of the regular consultation rooms. After the child entered the room, the robot (either the neutral or personal one) introduced itself and asked for the child's name, age, favourite colour and activity, and explained the quiz. They played the quiz together, whereby, in both conditions children and robot were competing against each other, by answering the most questions correctly. After playing the quiz, the child completed a questionnaire. At the second and third sessions, the procedure for the child was repeated. During the first session, parents also filled in a questionnaire. The experiment was set up in one room at the outpatient clinic and the parents were invited to stay in the room during the experiment. The first session took approximately 50 minutes, covering introduction (5 minutes), completing a pre-test (10 minutes), playing with robot (25 minutes) and completing a post-test (10 minutes). The second and third sessions approximately 40 minutes, covering completing a pre-test (5 minutes), playing with robot (25 minutes) and completing a post-test (10 minutes).

The child-robot interaction was partly Wizard-of-Oz (WoOz). As described in the pilot preceding the current study (Blanson Henkemans et al., 2013), the robot behaved autonomously, but the experiment leader partly simulated the dialogue and the audio sensors. The experiment leader instructed the robot system which phase of the interaction to start (i.e., introduction, explanation of the quiz, quiz, and closing) and typed what the child was saying to the robot (for example, the child's name and answers given to the robot's question). To minimize potential influence of the experiment leader on the child-robot interaction, the behaviour of the robot was fully scripted (i.e., followed a prescribed routine). The personal robot had a number of additional behaviours in comparison with the neutral robot, which were based on the SDT, as described in section 2.2. Self-determination theory for personalised robot behaviour. Per condition, the children had similar interaction and dialogue with the robot. Only the quiz questions varied, which were randomly presented to the child and robot (see section 2.1. Quiz to learn about diabetes for further details).

3.3. Measures

At the outset of the study, we asked the parents for their children's demographic details and medical background. Collected HbA1c measures were standardized according the

IFCC reference system (Hoelzel et al., 2004). All children filled in a questionnaire about their self-management behaviour using a Dutch translation of the Self-Care Inventory (SCI). The SCI was developed by La Greca and includes 14 items (La Greca, 2004). The questionnaire consists of four subscales: blood glucose management, insulin and food regulation, exercise and emergency precautions. The answers can be filled in on a five-point Likert scale: 1 (I never do this) to 5 (I always do this as recommended without fail). When the SCI was used with children in the past, internal consistency was .77 or higher (La Greca, 2004; Weinger et al., 2005).

To assess Health-Related Quality of Life (HRQoL), the Dutch version of the "Questionnaire for Young people with diabetes" (DISABKIDS) was used. The DISABKIDS group developed a European instrument that measures the Health-Related Quality of Life in children and adolescents with a chronic medical condition and their parents (Baars et al., 2005). The impact scale has a Cronbach's alpha of .84. There are 12 questions about how a patient has felt in the last four weeks that require answers on a 5-point Likert scale from 1 (Never) to 5 (Always). The time period covered by the questionnaire was adapted to "last month" in the last three questions since originally these refer to the burden of the diabetes in the last year, and the time between the measurements was about one and a half months. This amendment was made in consultation with a developer of the DISABKIDS.

To test the difference between the neutral and personal robot, the children in the robot groups were questioned during the study about determinants of self-determination. They were asked about the level of autonomy, competence and relatedness they experienced while playing the quiz with the personal or neutral robot. This was done using a translation of the Basic Need Satisfaction in Relationships Scale (La Guardia et al., 2000), which was designed to address need satisfaction in particular relationships. In this study, we used it to survey the child's relationship with the robot. The instrument consists of nine questions (for example, “When I am with the robot, I feel free to be who I am”, “When I am with the robot, I feel like a competent person”, and “When I am with the robot, I feel loved and cared about”). Each item was rated on a scale from 1 (not at all) to 7 (very much). This instrument has been used in the past to survey a range of sample groups, including children (Milyavskaya et al., 2009).

The participants were also asked about the amount of pleasure they had with the robot and the quiz, their motivation with respect to playing the quiz, and their diabetes knowledge. Pleasure with the robot and the quiz was measured after each session on a seven-point Likert scale using emoticons representing 1) Horrible; 2) Not pleasurable at all; 2) Not so pleasurable; 3) Neutral; 5) Somewhat pleasurable; 6) Pleasurable; 7) Very pleasurable. The children could also say in their own words what they liked and disliked about playing the quiz with the robot. Motivation was measured through the number of rounds the children decided to play and their desire to play the quiz in a fourth session as a hypothetical option.

Diabetes knowledge was measured with a diabetes knowledge questionnaire, covering 30 questions on diabetes and self-management. It was administered at the beginning of the study as baseline and after each quiz session. The order of the questions and the order of the answers per question were randomized. Also, we did not provide feedback to the children on the questionnaire. This was to minimize a learning effect from completing the questionnaire. The diabetes knowledge questionnaire was based on the questionnaire developed for the pilot with the health-care professionals from the WKZ and refined in collaboration with the professionals from the Gelderse Vallei Hospital. The questionnaire and also the questions of the quiz played with the robot stemmed from materials used at the hospital (in other words, folders, booklets and websites) and were reviewed by the diabetes nurses from the different clinics. As a result, consistency between the education provided during the study and during care as usual was guaranteed. In each questionnaire, the questions and multiple-choice answers were randomised.

Finally, interaction between the child and the robot was captured on video and audio. The pilot study showed that there was a distinct difference in children's engagement in the interaction over time (Blanson Henkemans et al., 2013). To further explore these differences, we collected and analysed qualitative information (based on video observations) about the children's facial expressions, gaze, body posture and things they said to the robot over the course of the different sessions.

These recordings were then coded and analysed, with the focus being on facial expressions, gaze, body posture, and spontaneous verbal utterance (Table 4 lists the coding scheme). Coding items were derived from earlier exploratory observations conducted during the pilot study (Blanson Henkemans et al, 2013). The items observed during the pilot study were further refined with directions from the MUMIN annotation scheme, 'a general instrument for the study of gestures and facial displays in interpersonal communication, in particular the role played by multimodal expressions for feedback, turn management and sequencing' (Allwood et al., 2005). Also, we looked at the descriptions of emotions given by Du et al. (2014) for the items regarding facial expressions. Interaction was coded using Noldus Observer XT 11, which facilitates the coding of point events (such as laughing out loud) and states (such as leaning on the table).

The coding scheme was tested for inter-rater validity before coding all videos. We referred to Cohen's Kappa scale of agreement, which states that an agreement of 0.80 and above as substantial (Cohen, 1960). Two coders independently rated five videos. Their scores were compared for each video. For these five videos, there were 11 items that varied more than 0.10, ranging from 0.47 to 0.76. The coders looked at the videos together and discussed the moments where the coders disagreed on the scoring. The moments were discussed until consensus was found, which ensured that the coding of the remaining videos was reliable. If consensus could not be found, the description of the item further elaborated. This was the case for item "Inquiring" and item "Leans backwards". In these cases, we gave more detail to the description, respectively, 'The child looks inquiring, that is to say the child observes an object, such as robot or tablet, intensely' and 'Child leans backwards in chair, for example, reclines head on back of chair, slouches in chair'.

3.4. Statistical analysis

Data were checked for normal distribution using graphical summary of data, assessment of skewness, descriptive statistics, and tests of normality. For initial between-group comparisons of data, t-tests were carried out on the change in variables over time. We also measured the interaction effect of the response variable group on participants' perceived pleasure, motivation and knowledge. Finally, we compared level of engagement through facial expressions, gaze, body posture and spontaneous verbal utterances (frequencies and length) coded in the captured video and audio material of the children playing with the personal and neutral robots.

4. Results

4.1. Participants

As shown in Table 2, 27 children (13 boys and 14 girls) participated in the study. One child assigned to the neutral robot group dropped out before the final session and his data was excluded from the analysis. The minimum age was 7 and the maximum age was 14 (M= 11.04, SD=1.71). Children were attending primary (n=20) and secondary (n=7) school. They had been diabetes patients for an average of 57 months (SD=27.67).

The minimum HbA1c was 51 mmol/mol (6.8%) and the maximum 91 mmol/mol (10,5%) (M=67.91, SD=10.44). On a scale from 1 (lowest) to 5 (highest), their SCI score was an average of 3.60 (SD=.52) and the HRQoL score was 3.44 (SD=.66) on average. The children had a pump (n=20) or used an insulin pen (n=7) for their diabetes regulation.

Of these children, 16 children (seven boys and nine girls) were assigned to the robot group (eight children to the personal robot and eight to the neutral one). The minimum age was 7 and the maximum age was 12 years (M=9.94, SD=1.20). Children were attending primary (n=15) and secondary (n=1) school. They had diabetes for an average of 54 months (SD=27.19). The minimum HbA1c was 51 mmol/mol (6.8%) and the maximum 82 mmol/mol (9.6%) (M=69.23, SD=9.92). On a scale from 1 (lowest) to 5 (highest), their SCI score was an average of 3.60 (SD=.54) and the HRQoL score was 3.26 (SD=.63) on average. The children had a pump (n=13) or used an insulin pen (n=3) for their diabetes regulation.

Eleven children (six boys and five girls) were assigned to the care as usual group. The minimum age was 11 and the maximum age was 14 (M= 12.55, SD=1.04). Children were attending primary (n=5) and secondary (n=6) school. They had been diabetes patients for an average of 59 months (SD=28.86). The minimum HbA1c was 51 mmol/mol (6.8%) and the maximum was 96 mmol/mol (10.9%) (M=67.64, SD=11.81. On a scale from 1 (lowest) to 5 (highest), their average SCI score was 3.59 (SD=.51) and their average HRQoL score was 3.71 (SD=.64). The children had a pump (n=14) or used an insulin pen (n=3) for their diabetes regulation.

Although the children in the control group were significantly older than the children in the robot group ($F(25)=.024$, $P<.001$), both groups did not differ in baseline scores, regarding diabetes knowledge, number of months with diabetes, HbA1c or SCI and HRQoL scores.

4.2. Autonomy, competence, and relatedness

As can be seen in Figure 3, the children were scored for the determinants of perceived self-determination - autonomy, competence, and relatedness - in their relationship with the robot over the course of the three sessions. We also calculated a total average score for all three determinants. On average, the children with the personal robot scored 5.94 (SD=.69), 5.50 (SD=1.01) and 5.51 (SD=.90) for total self-determination in the three sessions. The children with the neutral robot scored averages of 5.16 (SD=1.30), 4.91 (SD=.55) and 4.40 (SD=.50) for total self-determination in the three sessions. Children's ratings of autonomy, competence and relatedness were not normally distributed and we conducted a non-parametric test. When the two robot groups were compared, significant difference was found between the total SDT scores over time. However, the scores for the children who played with the neutral robot were significantly lower in the third session for perceived competence (Z=2.69, P=.007) and for total SDT (Z=2.33, P=.02).

4.3. Pleasure

As Figure 4 shows, the children rated the perceived pleasure with the personal and neutral robot for the three sessions on a scale of 1 (not at all) to 7 (a lot). Overall, the children gave the robot an average rating of 6.44 (SD=.96), 5.75 (SD=1.24), and 6.00 (SD=.97) (t(15)=1.70, P=.11) for the three sessions. The average pleasure ratings for the personal robot were 6.56 (SD=.73), 6.00 (SD=1.32) and 6.44 (SD=.73) for the three sessions. The average pleasure ratings for the neutral robot were 6.29 (SD=1.25), 5.43 (SD=1.13) and 5.43 (SD=.98). The children's ratings of pleasure with the robot and the quiz were not normally distributed and we conducted a non-parametric test. When the two robot groups were compared, it was found that the children who played with the neutral robot scored significantly lower in the third session for perceived pleasure with the robot (Z=2.06, P=.04).

In addition, children rated the perceived pleasure with the quiz with the personal and neutral robot on a scale of 1 (none at all) to 7 (a lot). Overall, the children gave the robot average ratings of 5.81 (SD=1.11), 5.31 (SD=1.13), and 5.50 (SD=1.03) (t(15)=1.05, P=.21) for the three sessions. The average pleasure ratings for playing the quiz with the personal robot were 6.11 (SD=.93), 5.22 (SD=1.30) and 5.88 (SD=1.05). The average pleasure ratings for playing the quiz with the neutral robot were 5.43 (SD=1.27), 5.43 (SD=.98) and 5.00 (SD=.82). When the two robot groups were compared, no significant differences were found in perceived pleasure with the quiz (Z=1.70, P=.09).

4.4. Motivation to play quiz with robot

As Table 3 shows, children with the personal robot played 6.00 (SD=.00), 5.89 (SD=.33) and 5.89 (SD=.33) quiz rounds on average in the three sessions. Children with the neutral robot played 6.00 (SD=.00), 5.71 (SD=.76) and 5.29 (SD=.49) rounds. When comparing the two robot groups with a Chi-square test, it was found that the children who played with the neutral robot played significantly fewer rounds on average in the third session ($\chi2(1)=6.11$, P=.04).

The children were also asked after session three whether they would have liked to play a fourth session, if possible. The children with the personal robot all answered in the affirmative. Four of the children with the neutral robot said they would have liked to play a fourth session. When comparing the two robot groups with a Chi-square test, it was found that significantly fewer children in the neutral robot group wanted to play a fourth time ($\chi2(1)=4.75$, P=.03). Arguments for playing a fourth time included: “He is fun”, “He is nice”, “He is smart and I want to learn more” and “He is sweet and friendly”. Arguments against playing a fourth time were, amongst others, “It takes time”, “It is fun, but three times is enough”, “After three times it becomes a bit boring”, and “It is a bit one-sided”. When we compared the personal and neutral robot, we found that the majority of the children who interacted with the personal robot felt he was “friendly” or “sweet” (n=5), whereas the majority of children who played with the neutral robot felt he was “funny” (n=4).

4.5. Knowledge

Figure 5 shows that the number of diabetes questionnaire items answered correctly, over the course of three sessions, by children assigned to the personal robot, the neutral robot and the control group. The number of correctly answered questions at session one was, respectively, 19.89 (SD=3.05), 21.00 (SD=3.06), and 21.36 (SD= 3.47). After session three, they answered, respectively, 26.89 (SD=.1.54), 25.86 (SD=2.19), and 22.82 (SD=3.19) questions correctly. After session three, the children who played the quiz with the neutral robot answered on average as many questions correctly as the children who played with the personal robot (P=.23). When the robot groups were compared with the control group after session three, it was found that the children who played with the robot answered on average significantly more questions correctly than the children who did not play the quiz with the robot ($F(1,45)=7.27$, $P=.001$).

4.6. Children’s engagement with personal and neutral robot

A total of 43 videos were coded and analysed (we failed to record seven interactions in the first session) to measure the level of engagement during the child-robot interaction. One video of an interaction in session 1 ended prematurely. In one interaction in session 2, the robot broke down for approximately 20 minutes. Data were adjusted to the actual interaction time. The average interaction time with the personal robot was 1433 seconds (SD=288.48), and the average interaction time with the neutral robot was 1273 seconds (SD=299.45) (P=.14).

Table 4 lists the average score of items per category and per session. The following items were significantly different for the children interacting with the personal or neutral robot. The children sat up straight more with the personal robot than with the neutral robot in sessions 1 and 3 ($F(7)=3.12$, $P=.01$; $F(14)=1.83$, $P=.01$). They smiled more often in the group with the personal robot during all three sessions ($F(7)=.05$, $P=.007$; $F(14)=7.85$, $P=.04$; $F(14)=1.95$, $P<.05$). They also looked more inquisitively at the personal robot in sessions 1 and 3 ($F(7)=.04$, $P=.01$; $F(14)=.38$, $P=.05$). They looked more at the personal robot than the neutral robot in session 1 and 3 ($F(7)=.04$, $P<.001$; $F(14)=.36$, $P=.05$). They made more short positive utterances when interacting with the personal robot in all three sessions ($F(7)=1.68$, $P=.001$; $F(14)=7.84$, $P=.02$; $F(14)=10.54$, $P<.001$). Finally, with the personal robot, the children used the robot's name (Charlie) more often than children with the neutral robot in sessions 2 and 3 ($F(14)=110.52$, $P=.04$; $F(14)=10.52$, $P<.05$).

A number of observations were made when coding the videos. Firstly, the children expressed annoyance (a total of 40 times) and boredom in a number of situations: when quiz questions were repeated, when the robot repeatedly asked the child if he or she wanted to continue or not, and when the utterances of the robot and child overlapped. Children expressed their boredom by sighing, rolling their eyes, yawning, leaning backwards in their chair, and drooping the corners of their mouths.

Secondly, we noticed two patterns in the children's behaviour. Children frequently looked up at the robot after finishing reading a quiz question to the robot. When the robot spoke a child's name, made a large gesture, or made a joke, the children paid more attention to the robot. After a personal question was put by the robot ("What is your favourite sport", for example), the children looked around to think about the answer.

Thirdly, we found that younger children were more involved in playing the quiz with the robot. We allocated the children to two age groups using median split. During the all sessions, younger children spent more time leaning towards the robot (M=25.00, SD=6.04; M=12.40, SD=7.38; M=10.60, SD=6.48) than older children (M=3.25, SD=6.50; M=4.33, SD=4.08; M=3.83, SD=1.94), ($F(7)=.04$, $P=.001$; $F(14)= 1.90$, $P=.03$; $F(14)= 7.01$, $P=.03$).

5. Discussion and Conclusions

Repeatedly playing a quiz at an outpatient clinic over a prolonged period of time (i.e., 6-7 weeks) with a social robot such as the Nao helped children with diabetes to learn more about their illness and how to manage it. After three sessions, children thought they had more pleasure with a personal robot, that is to say a robot that provides 1) flexibility in the interaction, feedback and encouragement, 2) challenges the child, 3) elicits and acknowledges emotions, and 4) refers to the child's interests during the interaction. A personalised robot also fulfils more the children's needs for autonomy, competence and relatedness while the quiz is being played. This enhances the children's motivation to continue playing the quiz, which is reflected in the children's behaviour: children with the personal robot paid more attention to the robot (in other words, they sat up straight looking at the robot), they were more social (in other words, they used the robot's name) and more expressive (they made more positive, negative and neutral utterances and smiled and giggled more).

5.1. Ongoing play of self-management education games with a personal robot

To further design a personal robot that plays educative games over a longer period of time and supports self-management, we made changes to the original quiz, the child-robot interaction and the study design proposed in the pilot study (Blanson Henkemans et al., 2013). To improve the quiz, we enlarged the questions database. The results show that the children felt the quiz was as pleasurable at the end of the study, as at the beginning. This is an improvement on the pilot study, in which the children clearly expressed a dislike of the quiz over time, due to the repetition of the questions. Nevertheless, children did respond with annoyance when questions were repeated. We are therefore faced with a trade-off between repeating questions to help the child learn about their illness and the chance of annoying them by questions they already know. This underlines the importance of tailoring the questions to the knowledge level of the child.

The current study showed that children felt that the personal robot was more pleasurable than the neutral robot and they were more motivated to continue playing. Still, they did not find playing the quiz with the personal robot more pleasurable. This suggests that the personalization of the robot character affects how the children experience the robot, but not necessarily the quiz. To make the quiz itself a more pleasurable experience, in addition to tailoring the quiz, it is advised to add features. Examples are offering variation in the type of questions (e.g., multiple choice and open questions) and adding a video and pose questions about its content.

To fulfil the children's need for relatedness and encourage them to take the initiative more during the interaction, the personal robot invited the child to ask personal questions at the beginning of each session. We found no differences in relatedness scores between the personal and neutral robots. In addition, the audio/video data showed that few children were actually willing to ask the robot personal questions. We may have to conclude that simply inviting the child to ask questions at the beginning of the interaction is not a successful strategy in terms of fulfilling the children's need for relatedness or encouraging them to show more initiative. Other strategies to encourage the child to feel related and show initiative could be more successful. The audio/video data also showed that interaction felt static (non-spontaneous) and formal (functional). The child and robot sat opposite each other at the table, playing the quiz. A possible strategy could involve an informal and dynamic set-up in which the child and robot can move around the room more freely and physical contact is possible. Applying the strategy of inviting the child to ask personal questions later on, when the child and robot have had enough time to establish trust, may also be more beneficial.

Finally, we looked at changes in behaviours between the different sessions. On the one hand, observations of the audio/video recordings confirmed our findings based on the survey data. On the other hand, they also provided a number of new insights. Certain robot behaviours triggered the attention of the children, such as saying the child's name and making large gestures. Finally, we found that younger children became more absorbed in playing the quiz with the robot (that is to say that they did lean more towards the robot). Children also expressed negative emotions that were not explicitly reflected in the survey data, which were overall very positive. The first was annoyance and the second was an emotion outside the coding scheme, but which we interpreted as boredom (children sigh, roll their eyes, yawn, lean backwards in their chair, and the corners of their mouths droop). By watching the videos, we were able to identify situations that triggered these negative emotions, and therefore devise guidance for improvements in the further design of a personal robot for educative activities. Moreover, we suggest adding boredom as a focus for analysis.

5.2. Directions for the future of educational child robot interaction

Study results generated directions for future improvements (these directions will be worked out in the PAL-project, www.pal4u.eu). Firstly, the robot timed its verbal reactions badly on occasion. For example, it started to talk when the child was still talking or there was a long pause before the robot finally answered a child's question. Observations showed that a number of children were annoyed by the robot's bad timing (although other children did not mind at all). This timing issue may be a feature in a Wizard of Oz set-up, which was applied in this study. The use of conversational fillers - expressions such as "Hmmm", "Umm" - and head scratching could resolve this issue by signalling that additional information is on the way, keeping the speaking turn, and acknowledging/back-channelling (Pfeifer & Bickmore, 2009).

Secondly, although the children had pleasure with and learned from the quiz, children have their own favourite learning styles (Leite et al., 2010). Learning styles may be visual, auditory, reading and writing, kinaesthetic and/or tactile. Offering the child a choice between different types of activity that incorporate these learning styles would be a further improvement in the personal robot playing different educational programmes with children. Examples could include sorting games (visual and tactile), keeping a diary (writing) and/or watching and discussing an educational video clip (visual, auditory).

Thirdly, although the interaction and quiz questions were tailored, the personal robot did not take into account differences in the children's cognitive, emotional, physical and social skill levels. Scott (2013) underlines the importance of understanding the current skill level, as it affects how the child manages his or her illness. This can be seen, for instance, in how children at the age of eight increase their muscle control, show more complex emotions, start to express opinions and develop close friendships. Children at the age of eleven may express puberty, become less egocentric, develop reasoning skills, and show empathy towards others. As a result, children with different skill levels approach their diabetes very differently. To be more successful in teaching the children how to manage their diabetes, it is important to tailor the interaction and educational activities (mostly type and content) to individual skill levels.

Finally, the child-robot interaction took place at the outpatient clinic. However, children apply self-management throughout the day at different locations (such as home and school), and in collaboration with others, including parents and peers. In the Netherlands, children visit the diabetes clinic four times a year only and it would be useful if children could continuously consult a personal computer assistant about the illness and how to manage it. We would therefore suggest combining a physical assistant (such as the Nao robot) with a virtual assistant on a mobile device such as a smartphone. The virtual assistant should have the same form, functions, and architecture. A major benefit would be that the virtual assistant, which also has a built-in location recogniser, can facilitate situated learning. That is to say, learning in the same context, such as the home, school and outside, where it is applied (Lave & Wenger, 1990). This approach has proven to be more effective in the acquisition of content and pedagogy than traditional learning styles (Meyers & Lester. 2013). Illustratively, Looije et al. (2012) compared a virtual agent on a screen with a physical robot on the aspects of performance (learning), attention and motivation. Children played a health quiz with both the robot and the virtual agent. Results showed that, although the children preferred the robot, lack of embodiment did not affect the children's' performance and motivation. Other studies found that virtual agents are anticipated as social actors in children. Through expressing emotion, they can further contribute to motivation and learning in children (Kopp et al., 2003; Kessens et al., 2009).

5.3. Limitations

Children played three sessions with the robot, which limits our knowledge on the ongoing effects of personalized robot behaviour on their pleasure and motivation. After three sessions, we found that motivation fell off slightly. However overall, the level of pleasure and motivation remained high. Also, a number of children working with the neutral robot said they did not want to play a fourth time. Our data provide no clear indication of the time span after which children's interest in the personal robot starts to decline.

Related to previous limitation, the difficulty level of the quiz questions were not established, in relation to the children's knowledge level, and thus we cannot state its possible impact on the children's motivation. One can imagine that quiz questions that are too easy or too hard to answer, may have a negative effect on the motivation of children to play the quiz. We aimed at minimalizing this effect by randomizing the quiz questions (both general and diabetes related questions). Still, for future application of the quiz, we advise to determine and match the difficulty level of questions in relation to the knowledge level of the child. For example, in accordance with the theory zone of proximal development, "an area of learning that occurs when a person is assisted by a teacher or peer with a skill set higher than that of the subject" (Copple & Bredekamp, 2009). Thus, it could be beneficial to match the topic difficulty level of the questions with the knowledge of the child and have the robot, who's knowledge level is slightly higher, offers assistance the child to further develop his or her knowledge. Thus, as the child improves his or her knowledge, the subject will change (e.g., from counting carbs to injecting insulin) and difficulty (e.g., make the question more complex).

A third limitation was the use of a newly developed, non-validated coding scheme. The existing coding schemes focusing on child-robot interaction such as the one used by Oh & Kim (2010) did not fully satisfy our requirements in regard to the level of detail needed to test our hypothesis (that a personalised robot affects children's behaviour when a quiz is being played). Nevertheless, our coding scheme was based as much as possible on more generic, validated, coding schemes such as MUMIN (Attwood et al., 2005) and the description of facial expressions by Du et al. (2104). Our study showed that the coding scheme was useful, as we were interested in the combination of gaze, body posture, verbal utterances and facial expressions. We will continue to apply the coding scheme and we invite other researchers to do so and to share their lessons learned, for example by defining other emotions such as boredom. This would help greatly in improving the coding scheme for child-robot interaction research.

5.4. Conclusions

Playing an educative quiz with a social and personal robot over a prolonged period of time can help children to learn more about their illness and how to self-manage it. Moreover, a robot applying SDT based strategies, furthering the child's sense of autonomy competence and relatedness, is pleasurable and motivating. These strategies entail offering free choice and constructive feedback, acknowledging feelings and moods, encouraging competition, and building a rapport. By contributing to their knowledge about diabetes, it could help the children to improve their self-management and prevent complications in later life.

Acknowledgements

We would like to thank the Paediatrics Department of the Gelderse Vallei Hospital in Ede for their collaboration. We also wish to acknowledge valuable input from the children and their parents.

Conflict of interest

The authors report no conflict of interest in this work.

Role of funding source

This research was partly funded by the FP7 program ALIZ-E.

References

Allwood, J., Cerrato, L., Jokinen, K., Navarretta, C., Paggio, P., 2007. The MUMIN coding scheme for the annotation of feedback, turn management and sequencing phenomena. Lang. Resour. Eval. 41, 3-4.

American Diabetes Association, 2003. Standards of Medical Care for Patients With Diabetes Mellitus. Diabetes Care 26, s33-s50

Baars, R.M., Atherton, C.I., Koopman, H.M., Bullinger, M., Power, M., the DISABKIDS group, 2005. The European DISABKIDS project: development of seven condition-specific modules to measure health related quality of life in children and adolescents. Health Qual. Life. Out. 3, 70. Retrieved from http://www.hqlo.com/content/pdf/1477-7525-3-70.pdf

Baranowski, T., Buday, R., Thompson, D.I., Baranowski, J. 2008. Playing for real: video games and stories for health-related behavior change. Am. J. Prev. Med. 34, 74-82.

Blanson Henkemans, O.A., Hoondert, V., Schrama-Groot, F., Looije, R., Alpay, L.L., Neerincx, M.A., 2012. “I just have diabetes”: Children’s need for diabetes self-management support and how a social robot can accommodate. Patient Intelligence. 4, 1-11.

Blanson Henkemans, O.A., Bierman, E.B.P., Janssen, J., Neerincx, M.A., Looije, R., Van der Bosch, H., Van der Giessen, J.A., 2013. "Using a robot to personalise health education for children with diabetes type 1: a pilot study". Patient. Educ. Couns. 92 (2): 174-181.

Cohen, J. (1960). A coefficient of agreement for nominal scales. Educ. Psychol. Meas. 20, 37–46

Copple, C., Bredekamp, S. (2009). Developmentally appropriate practice in early childhood programs. Washington, DC: National Association for the Education of Young Children.

Couch, R., Jetha, M., Dryden, D.M., Hooten, N., Liang, Y., Durec, T., Sumamo, E., et al., 2008. Diabetes education for children with type 1 diabetes mellitus and their families. Evid. Rep. Technol. Assess. 166,1-44.

Deci, E.L., Ryan, R.M., 2000. The “what” and “why” of goal pursuits: Human needs and the self-determination of behavior. Psychoanal. Inq. 11, 227-268.

Deci, E.L., 1975. Intrinsic motivation, Plenum, New York.

Dedding, C., 2012. Delen in macht en onmacht: Kindparticipatie, in de (alledaagse) diabeteszorg [Sharing power and powerlessness: Children participation in (daily) diabetes care]. Harper & University of Amsterdam, Amsterdam. URL: http://dare.uva.nl/document/146511, accessed December, 2014.

DeShazo, J., Harris, L., Pratt, W., 2010. Effective Intervention or Child's Play? A Review of Video Games for Diabetes Education. Diabetes Technol. Ther.12, 815-822.

Diehl, J.J., Schmitt, L.M., Villano, M. Crowell, C.R., 2012. The clinical use of robots for individuals with Autism Spectrum Disorders: A critical review. Res Autism Spect Dis. 6, 249–262

Du, S., Tao, Y., Martinez, A.M., 2014. Compound facial expressions of emotion. P. Natl. Acad. Sci. USA. 111, 1454-1462.

La Greca, A.M., 2004. Manual for the Self Care Inventory: Description and Psychometric Support. University of Miami, Miami. URL: https://www.psy.miami.edu/faculty/alagreca/SCI_manual_2004.pdf, accessed December, 2014.

Hoelzel W., Weykamp, C., Jeppsson, J.O., Miedema, K., Barr, J.R., Goodall, I., Hoshino, T., et al., 2004. IFCC reference system for measurement of hemoglobin A1c in human blood and the national standardization schemes in the United States, Japan, and Sweden: a method-comparison study. Clin. Chem. 50, 166-174.

Hoey, H., Aanstoot, H.J., Chiarelli, F., Daneman, D., Danne, T., Dorchy, H., 2001. Good metabolic control is associated with better quality of life in 2,101 adolescents with type 1 diabetes. Diabetes Care, 24,1923-1928.

Hood, K.K., Peterson, C.M., Rohand, J.M., Drotar, D., 2009. Association between adherence and glycemic control in pediatric type I diabetes: A meta-analysis. J. Pediatr. 124, e1171-e1179.

Janssen, J.B., Wal, C.C. van der, Neerincx, M.A., Looije, R., 2011. Motivating children to learn arithmetic with an adaptive robot game. Proceedings of the ICSR 2011 3rd International Conference on Social Robotics. Elsevier B.V., Amsterdam, the Netherlands.

Kalyva, E., Malakonaki, E., Eiser, C., Mamoulakis, D., 2011. Health-related quality of life (HRQoL) of children with type 1 diabetes mellitus (T1DM): Self and parental perceptions. Pediatr. Diabetes. 12, 34-40.

Kessens, J. M., Neerincx, M., Looije, R., Kroes, M., Bloothooft, G., 2009. Facial and vocal emotion expression of a personal computer assistant to engage, educate and motivate children. In Affective Computing and Intelligent Interaction and Workshops. ACII, 1-7.

Kopp, S., Jung, B., Leßmann, N., Wachsmuth, I., 2003. Max - A Multimodal Assistant in Virtual Reality Construction. KI, 17, 11.

La Guardia, J.G., Ryan, R.M., Couchman, C.E., Deci, E.L., 2000. Within-person variation in security of attachment: a self-determination theory perspective on attachment, need fulfillment, and well-being. J. Pers. Soc. Psychol. 79, 367-384.

Lave, J., Wenger, E., 1991. Situated learning: legitimate peripheral participation. Cambridge University Press, Cambridge.

Leite, W.L., Svinicki, M., Shi, Y., 2010. Attempted Validation of the Scores of the VARK: Learning Styles Inventory with Multitrait-Multimethod Confirmatory Factor Analysis Models. Educ. Psychol. Meas. 70, 323-339.

Levine, B.S., Anderson, B.J., Butler, D.A., Antisdel, J.F., Brackett, J., Laffel, L.M.B., 2001. Predictors of glycemic control and short-term adverse outcomes in youth with type 1 diabetes. J. Pediatr. 139, 197-203.

Lynne, S., Schilling, R.N., Grey, M., Knafl, K.A., 2002. The concept of self-management of type 1 children and adolescents: an evolutionary concept analysis. J. Adv. Nurs. 37, 87-99.

Looije, R., Neerincx, M.A., Cnossen, F. 2010. Persuasive robotic assistant for health self-management of older adults: Design and evaluation of social behaviors. Int. J. Hum. Comput. Stud. 68, 386-397.

Looije, R, Zalm, A.M. van der, Neerincx, M.A., Beun, R.J., 2012. Help, I need some body. The effect of embodiment on playful learning. In P Blazevic et al (Ed.), Proceedings 21st IEEE International Symposium on Robot and Human Interactive Communication. Piscataway, NJ: IEEE, 718-724.

Meyers, S., Lester, D., 2013. The Effects of Situated Learning Through a Community Partnership in a Teacher Preparation Program. SAGE Open. 3, 1-9.

Milyavskaya, M., Gingras, I., Mageau, G.A., Koestner, R., Gagnon, H., Fang, J. Boiché, J., 2009. Balance across contexts: importance of balanced need satisfaction across various life domains. Pers. Soc. Psychol. B. 35, 1031-1045.

Niemiec, C.P., Ryan, R.M., 2009. Autonomy, Competence, and Relatedness in the Classroom: Applying Self-Determination Theory to Educational Practice. Theor. Res. Soc. Educ. 7, 133-144.

Patterson, C.C., Dahlquist, G.G., Gyürüs, E., Green, A., Soltész, G., EURODIAB Study Group, 2009. Incidence trends for childhood type 1 diabetes in Europe during 1989-2003 and predicted new cases 2005-20: a multicentre prospective registration study. Lancet. 13, 2027-2033

Pfeifer, L.M., Bickmore, T., 2009. Should Agents Speak Like, um, Humans? The Use of Conversational Fillers by Virtual Agents. Lect Notes Comput. Sc. 5773, 460-466.

Przybylski, A.K., Rigby, C.S., Ryan, R.M., 2010. A Motivational Model of Video Game Engagement. Rev. Gen. Psychol.14, 154-166.

Qayyum, A.A., Lone, S.W., Ibrahim, M.N., Atta, I., Raza, J., 2010. Effects of diabetes self-management education on glycaemic control in children with insulin-dependent diabetes mellitus. JCPSP. 20, 802-805.

Ryan, R.M., Deci, E.L., 2001. On happiness and human potentials: A Review of research on hedonic and eudaimonic well-being. In S Fiske (Ed.), Ann. Rev. Psychol. 52,141-166.

Ryan, R.M., Rigby, C.S., Przybylski, A.K., 2006. The Motivational Pull of Video Games: a Self-Determination Theory Approach. Motiv. Emot. 30, 344-360.

Roper, S.O., Call, A., Leishman, J., Cole, R.G., Mandleco, B.L., Dyches, T.T., Marshall, E.S., 2009. Type 1 Diabetes: Children and Adolescents' Knowledge and Questions. J. Adv. Nurs. 65, 1705-1714.

Scott, L.K., 2013. Developmental Mastery of Diabetes-Related Tasks in Children. Nurs. Clin. N. Am. 48, 329-342.

Tielman, M., Neerincx, M.A., Meyer, J.-J.C., Looije, R. 2014. Adaptive emotional expression in robot-child interaction. HRI 2014: proceedings of the 2014 ACM/IEEE interaction conference on human-robot interaction, Bielefeld, Germany, 407-414.

Van Der Drift, E.J.G., Beun, R.-J., Looije, R., Blanson Henkemans, O.A., Neerincx., M.A., 2014. A remote social robot to motivate and support diabetic children in keeping a diary. . HRI 2014: proceedings of the 2014 ACM/IEEE interaction conference on human-robot interaction, Bielefeld, Germany, 463-470.

Wagner, V.M., Muller-Godeffroy, E., Von Sengbusch, S., Hager, S., Thyen, U., 2005. Age, metabolic control and type of insulin regime influences health-related quality of life in children and adolescents with type 1 diabetes mellitus. Eur. J. Pediatr. 64, 491-496.

Weinger, K., Butler, H.A., Welch, G.W., La Greca, A.M., 2005. Measuring Diabetes self-care; a psychometric analysis of the Self-Care Inventory-revised with adults. Diabetes Care. 28, 1346–1352.

WHO, 2010. Tackling chronic disease in Europe strategies, interventions and challenges. Copenhagen: World Health Organization on behalf of the European Observatory on Health Systems and Policies. URL: http://public.eblib.com/choice/publicfullrecord.aspx?p=557614, accessed December, 2014.

Legends

Table 1: A case study of a child interacting with the personal vs. neutral robot.

Table 2: Baseline characteristics of study participants, total and by group (N=28)

Table 3: Average number of quiz rounds played per session with the personal or neutral robot (N=17)

Table 4: Coding scheme for child-robot interaction and data from audio/video recordings (N=17)

Figure 1: Child playing quiz with robot on see-saw monitor

Figure 2: Flow diagram for the RCT

Figure 3: Average score for self-determination in total and by determinant with the personal or neutral robot for each session (N=17)

Figure 4: Children’s perceived pleasure with the personal and neutral robot and with the quiz over three sessions (N=17)

Figure 5: Children's diabetes knowledge with personal and neutral robot and care as usual, at baseline and over three sessions (N=28)

Table 1: A case study of a child interacting with the personal vs. neutral robot.

Non-personalized Charlie	**Personalized Charlie**
Kim enters the study room and sees Charlie sitting on a table. The eyes of Charlie have a standard white colour. Kim and Charlie start with the quiz. During the quiz, Kim and Charlie answer questions about diabetes and other non-diabetes related questions (e.g., "you are about to do some sports or other activity (like playing outside). Do you have to inject insulin or take a dextrose?"). After one round, Charlie and Kim are done with the quiz.	*Kim enters the study room and sees Charlie sitting on a table. Charlies eye colour is the favourite colour of Kim. Before starting the quiz, Kim can ask some personal questions to Charlie (e.g., "Where do you come from?"). During the quiz, Kim and Charlie answer questions about diabetes and other non-diabetes related questions. Charlie addresses Kim by mentioning her name and gives feedback on a question by also mentioning how Kim answered the question in a previous session. The quiz questions are also adapted to the sport Kim plays (e.g., "you are about to play a hockey game or do some other activity (like playing outside). Do you have to inject insulin or take a dextrose?"). Charlie also askes Kim what she thinks about the game and if she wants to continue playing or not.*

Table 2

	Robot (N=16)				Control group (N=11)				Total (N=27)			
Gender	7 boys; 9 girls				6 boy; 5 girl				13 boy; 14 girl			
	Min	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
Age	7	12	10.00	1.10	11	14	00	1.04	7	14	11.04	1.70
Diabetes since (months)	13	96	55.13	27.67	12	96	58.82	28.86	12	96	56.93	27.67
HbA1c	51	82	68.17	9.55	51	91	67.64	11.81	51	91	67.91	10.44
SCI (scale 1-5)	2.38	4.62	3.61	.55	2.46	4.23	3.59	.51	2.38	4.62	3.60	.52
HRQoL (scale 1-5)	2.15	4.23	3.26	.65	2.77	4.77	3.71	.64	2.15	4.77	3.44	.67

Table 3

	Session 1		Session 2		Session 3	
Number of rounds played	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Personal robot	6.00	.00	5.89	.33	5.89	.33
Neutral robot	6.00	.00	5.71	.76	5.29	49

Table 4

Item***	Description	Session 1				Session 2				Session 3			
		Personal (N=5)		Neutral (N=4)		Personal (N=9)		Neutral (N=7)		Personal (N=9)		Neutral (N=7)	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Body posture													
Sits down (initial state)	Child sits in chair	487.92	275.34	354.00	397,16	489.41	213.14	569,91	220,95	596.33	274.63	755.87	283.23
Sits up straight (event)	Child sits up	10.40*	4.22	2.00	2,45	6.44	6.58	2,86	2,27	9.67*	5.00	3.00	4.12
Leans backwards (state)	Child leans backwards in chair (for example, reclines head on back of chair, slouches in chair)	31.24	34.73	0.00	0.00	8.52	12.81	5,03	12,22	4.85	6.66	0.00	0.00
Leans forwards (state)	Child sits in chair, but leans forward	558.60*	157.67	65.28	130,56	156.29	164.54	158,25	118,35	124.78	118.22	68.09	62.18
Leans on table (state)	Child sits in chair, leans forward and leans on table (for example with elbows or forearms)	78.26	150.34	33.96	54,57	151.78	205.61	1,73	3,43	25.16	45.75	32.33	71.46
Stands up (state)	Child stands (in front of table and tablet, for example)	124.22	201.78	0.00	0.00	0.14	0.41	16,53	35,73	25.16	45.75	32.33	71.46
Bounces on/spins on/rolls with chair (state)	Child bounces on chair, spins round on chair, or rolls around on chair	103.60	148.42	227.87	353,35	395.61	291.77	271,27	207,88	423.19	217.93	267.17	216.83

Child turns tablet (event)	Child turns the tablet towards robot when it is its turn to do so.	12.40	7.23	6.25	7,23	16.11	6.45	15,43	4,24	13.33	1.73	14.71	3.50
Robot turns tablet (event)	The robot turns the tablet towards the child when it is its turn to do so.	8.60	3.13	4.50	5,20	6.78	3.70	8,57	3,10	10.00	0.71	9.43	2.23
Child helps robot to turn tablet (event)	Child turns the tablet towards him/herself when it is actually the robot's turn to do so but is unsuccessful	2.20	2.39	1.00	1,41	1.67	1.66	1,71	2,87	1.11	1.27	1.43	1.51
Cheers (event)	Child cheers by lifting hands or verbal cheer such as saying "hurray!" or "yay!"	0.80	0.84	0.25	0,50	0.22	0.67	0,14	0,38	0.44	0.73	0.00	0.00
Shakes/nods head (event)	Child moves head in a shaking or nodding fashion	7.40	3.05	5.25	8,54	3.11	4.20	1,57	2,07	5.56	7.04	3.00	4.93
Lifts shoulders (event)	Child shrugs shoulders	2.20*	1.64	0.00	0,00	2.78	5.02	0,71	1,50	1.00	1.32	1.71	1.11
Fiddles with hands (state)	Child fiddles with hands: for example, fiddles with fingers, hair, tablet, chair and/or wristband	16.60	8.29	4.00	5.66	17.22	10.78	12.75	8.91	16.22	6.85	17.57	13.64
Facial expression													
Neutral (initial state)	The child has a neutral facial expression	1239.07	221.98	545.46	672,29	1486.77	373.50	1353,24	426,93	1189.70	159.86	1132.55	133.57
Smile (event)	The child smiles, that is to say the child lifts the corners of the mouth and shows teeth	60.80*	19.64	15.40	20,68	49,22*	31,69	21,14	10,98	45,33*	24,70	25,14	10,87
Frown (event)	The child frowns, i.e., lowers eye brows and has wrinkles on the for head	5.80	4.27	1.25	1,50	3,78	3,63	5,14	5,96	5,56	4,75	5,86	6,20

Surprised (event)	The child looks surprised, that is to say the child opens the eyes wide open, lifts eyebrows, opens mouth, smiles	5.80	4.27	1.54	1.50	3.78	3.63	4,00	3,81	5.56	4.75	5.86	6.20
Shocked (event)	The child looks shocked, that is to say the child opens eyes wide open, opens mouth	1.60	1.14	0.25	0,50	1,22	1,30	0,29	0,76	3.00	2.45	3.14	2.67
Disgusted (event)	The child looks disgusted, that is to say the child frowns, curls upper lip	0.00	0.00	0.25	0,50	1.22	1.30	1.25	0.50	0.78	1.09	0.29	0.49
Inquiring (event)	The child looks inquiring, that is to say the child observes an object, such as robot or tablet, intensely	16.20*	4.55	5.50	5,26	8,78	4,52	8,43	3,55	7,33**	2,40	4,86	2,04
Pensive (event)	The child looks pensive, that is to say the child looks neutrally at nowhere in particular, but is still engaged in activity/interaction with robot and/or tablet	0.20*	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.11*	0.33	0.00	0.00
Annoyed (state)	The child looks annoyed, that is to say the child sighs, rolls his/her eyes, pouts	0.00	0.00	0.00	0.00	12.56	6.97	9.75	5.34	11.22	2.64	10.71	4.19
													Gaze
At screen (initial state)	Child looks at the screen of tablet PC containing quiz question, or the backside in anticipation for it to turn in the direction of the child	677.37	233.73	643.56	155.45	700.37	238.73	667,90	104,73	644.47	139.42	687.57	155.46
At robot (state)	Child looks at the robot	561.01**	101.88	81.15	116,45	317.76	129.85	317,76	129,85	237.74*	75.63	170.24	64.67
At parent (state)	Child looks at the parent in the room	47.44*	30.15	37.11	69.69	27.00	23.20	14.35	15.87	18.78	35.66	14.34	15.87

At experiment leader (state)	Child looks at the experiment leader in the room	27.91	12.31	30.26	62.15	28,71	29,81	33,87	24,69	14.86	9.48	12.42	10.74
Elsewhere (state)	Child looks elsewhere, such outside, under the table, to the ceiling, the wall next to the robot, and own hands	186.10	133.52	123.22	124.76	284.88	110.11	373,75	356,88	278.40	68.78	263.29	92.23
Verbal utterances child													
Short utterance pos (1-5w) (event)	Response of child to personal question with a positive connotation of between 1 and 5 words ("Yes, I like playing")	16.80**	2.59	5.25	4,11	13.44*	6.37	7,14	1,07	13.22**	3.38	6.43	0.98
Short utterance neg (1-5w) (event)	Response of child to personal question with a negative connotation of between 1 and 5 words ("No, I did not", for example)	1.00	1.22	0.55	0,50	1.56*	1.01	0,43	0,53	0.67*	0.87	0.14	0.38
Short utterance neutr (1-5w) (event)	Response of child to personal question with a neutral connotation of between 1 and 5 words ("My favorite colour is blue", for example)	8.80*	5.54	0.00	0,00	3.33*	3.24	0,43	0,79	2.78**	1.64	0.14	0.38
Medium utterance pos (6-10w) (event)	Response of child to personal question with a positive connotation of between 6 and 10 words ("I think playing the quiz is a lot of fun", for example)	0.80	0.84	0.00	0.00	0.67	1.32	0.00	0.00	0.11	0.33	0.14	0.38
Medium utterance neg (6-10w) (event)	Response of child to personal question with a negative connotation of between 6 and 10 words ("No, I didn't think the quiz was challenging", for example)	0.22	0.67	0.13	0.35	0.11	0.33	0.00	0.00	2.80	2.28	0.40	0.55
Medium utterance neutr (6-10w) (event)	Response of child to personal question with a neutral connotation of between 6 and 10 words ("Ok, I will see you next time", for example)	2.80	2.28	0.50	0,58	0.89	1.36	0,57	0,53	0.44	0.73	0.43	0.53

Long utterances pos (11+) (event)	Response of child to personal question with a positive connotation of 11 words or more (“I really enjoyed playing the quiz with you Charlie. See you soon.”, for example)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.33	0.00	0.00
Long utterances neg (11+) (event)	Response of child to personal question with a negative connotation of 11 words or more (“You already asked me that question. You still don’t know the answer?”, for example)	0.00	0.00	0.20	0.45	0.00	0.00	0.13	0.35	0.00	0.00	0.00	0.00
Long utterances neutr (11+) (event)	Response of child to personal question with a neutral connotation of 11 words or more (“I don’t know if you can catch up with my score. We will see.”, for example)	0.20	0.45	0.00	0.00	0.22	0.44	0.00	0.00	0.11	0.33	0.00	0.00
Laughs out loud (event)	Child laughs out loud	1.20	1.64	0.00	0.00	0.67	1.41	0.00	0.00	0.22	0.44	0.00	0.00
Giggles (event)	Child giggles	5.00*	6.20	0.60	1,34	3.33	2.55	1,00	1,53	3.67	4.56	1.25	1.58
Robot and child utterances overlap (event)	The robot and child talk at the same time. For example, child starts to give answer to quiz question and robot invites the child to give an answer	4.40*	1.34	1.25	2,50	5.33	5.59	5,86	4,14	5.56	3.61	4.43	3.46
Child says 'Charlie' (event)	The child uses Charlie’s name during the interaction	0.20	0.45	0.00	0.00	0.89*	1.05	0.00	0.00	0.89*	1.05	0.00	0.00

*P<.05; **P=.001; ***Events are counted in frequency; states are counted in seconds

Figure1

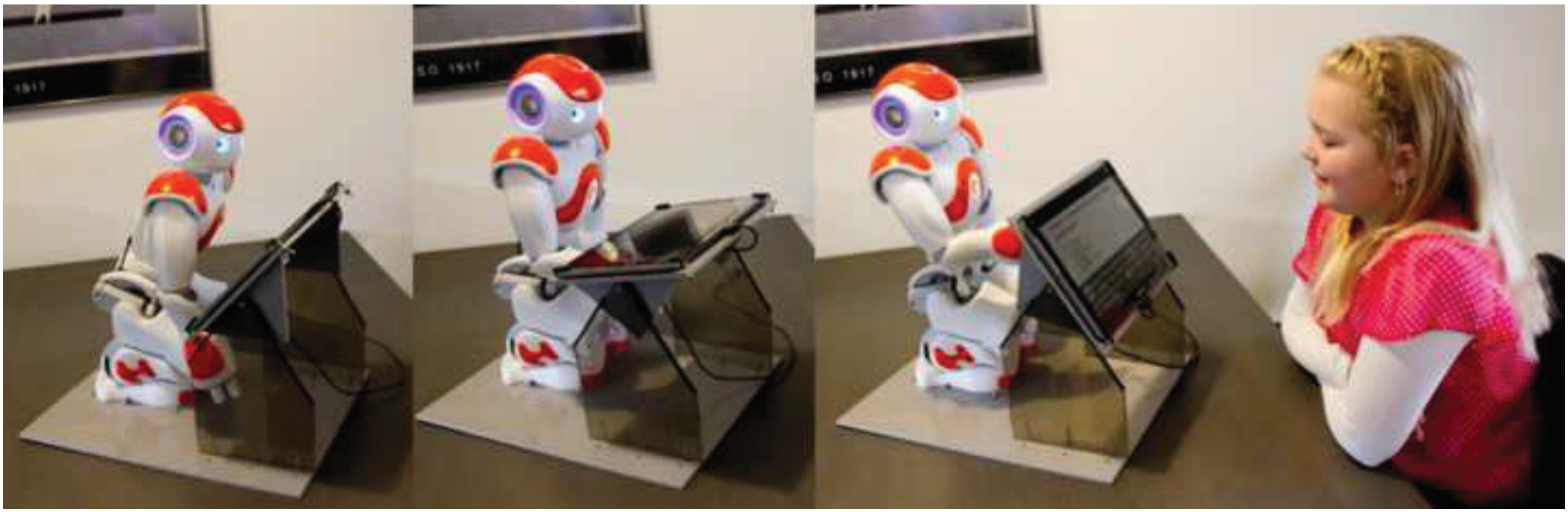

Figure2
Click here to download high resolution image

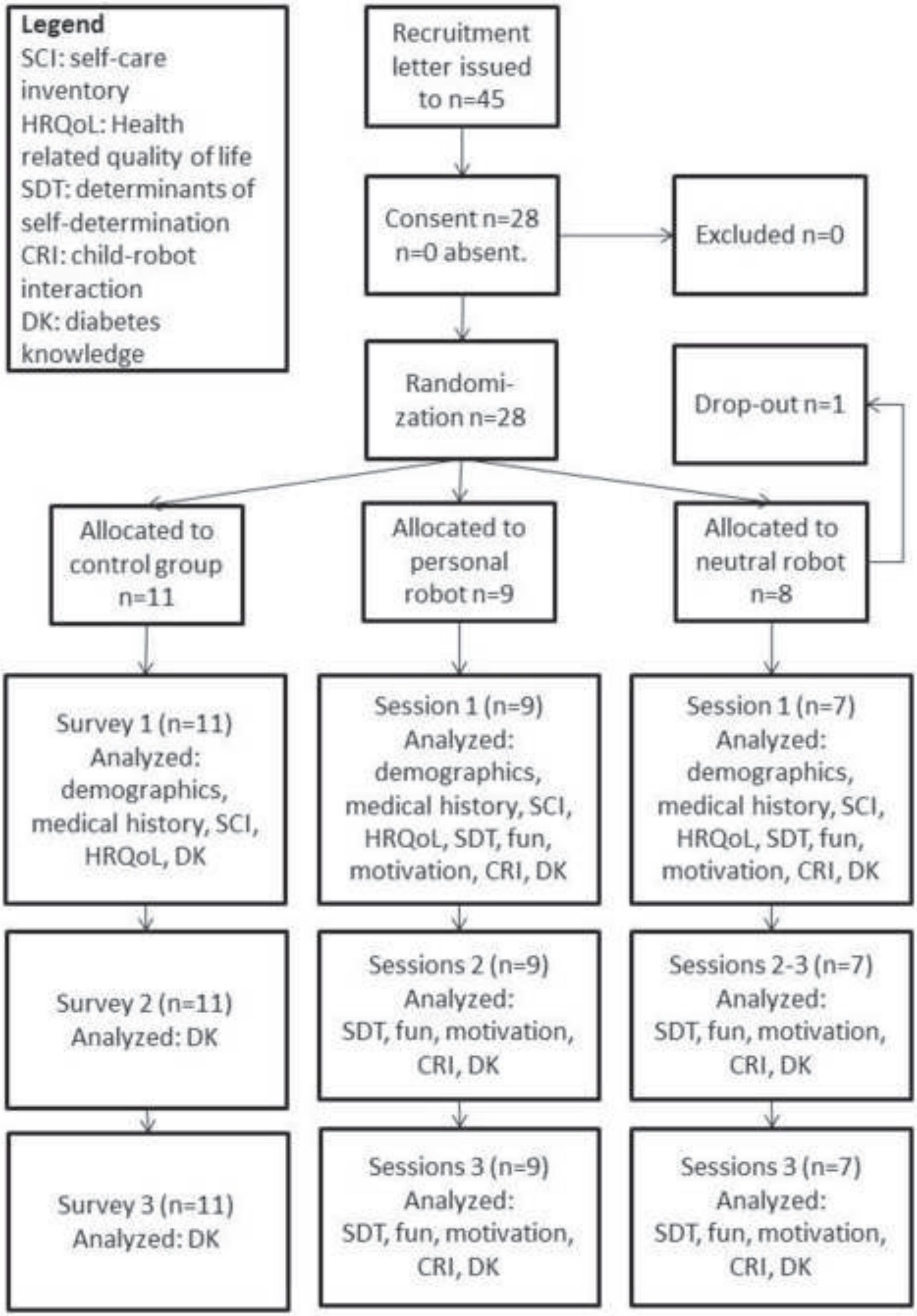

Figure3

Click here to download high resolution image

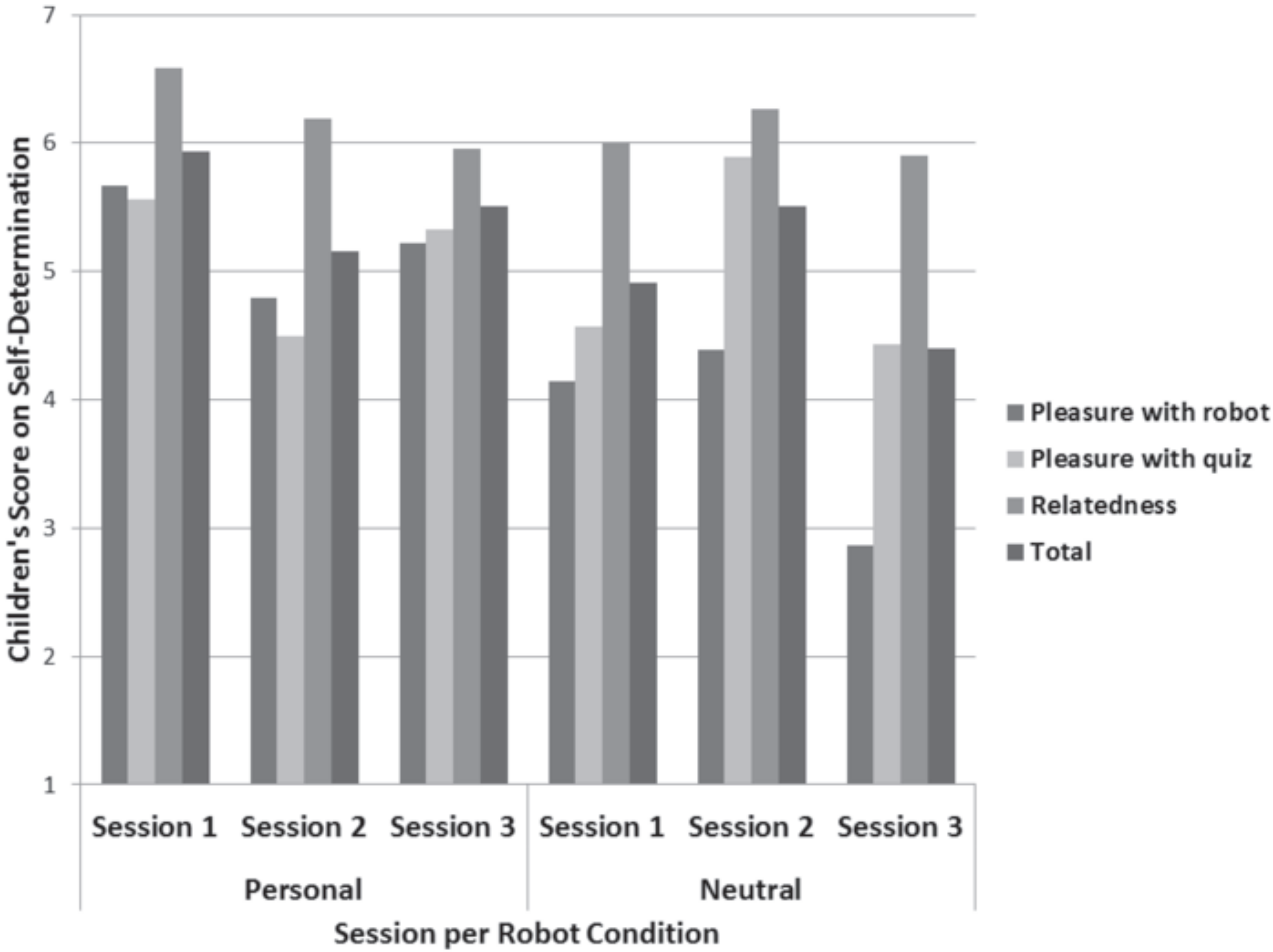

Figure5

Click here to download high resolution image

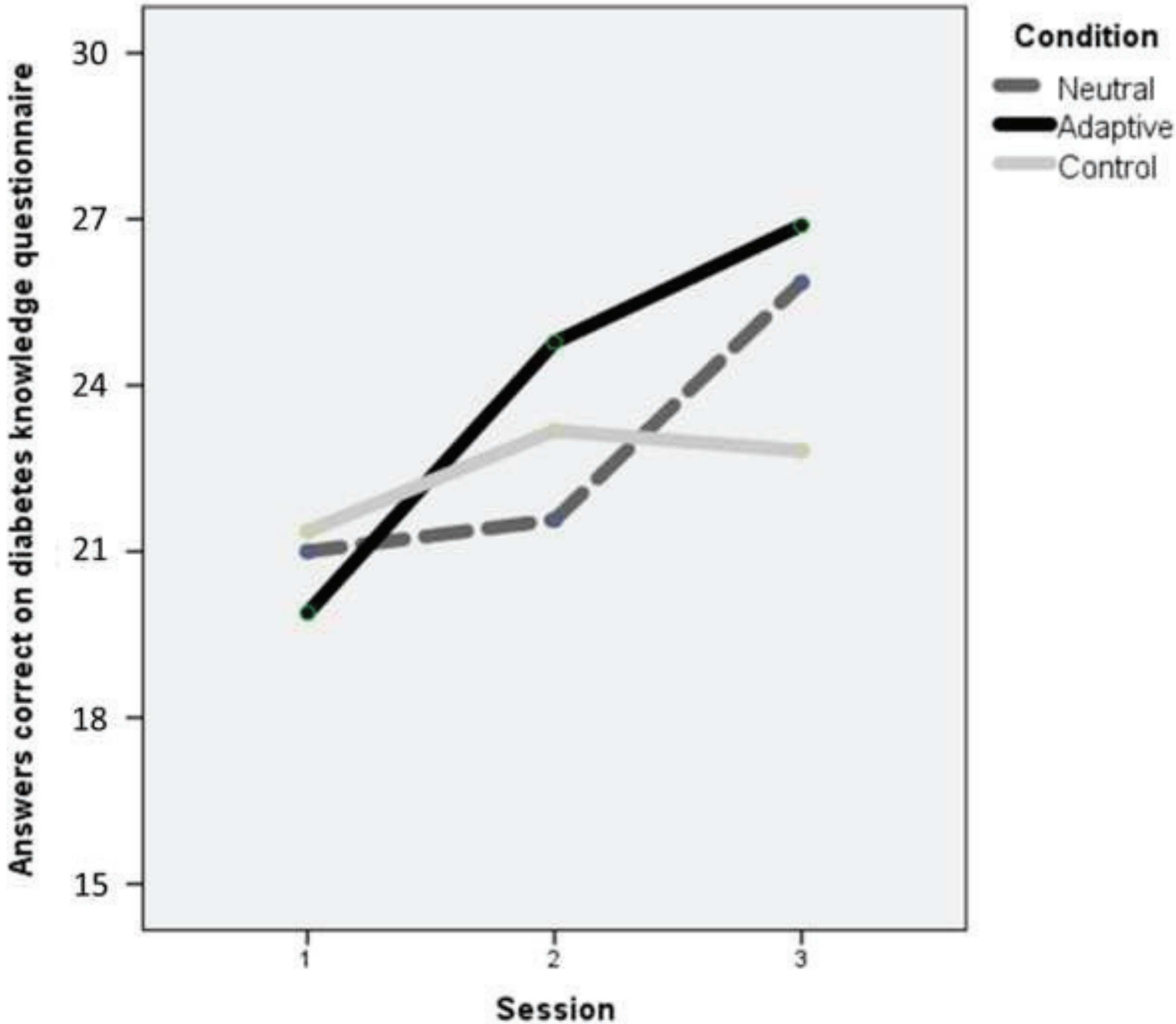

Figure4
Click here to download high resolution image